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VAMISTOR RESISTOR INVESTIGATION

Quality and Reliability Assurance Laboratory

May 1, 1973

NASA

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

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16. ABSTRACT

This report presents the results of the failure investigation conducted by MSFC on resistors produced by the Vamistor Division, Wagner Electric Corporation. This failure investigation included; failure analyses, chemical and metallurgical analyses, failure mechanism studies, seal leak analyses, and nondestructive stress tests. The data, information, conclusions, and recommendation presented herein can be helpful in assessing current usage of these resistors.

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MSFC - Form 3292 (May 1969)

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

LIST OF TABLES

SUMMARY

This report presents the results of a failure investigation conducted by MSFC on hermetically sealed thin film resistors produced by Vamistor Division, Wagner Electric Corporation. This failure investigation was initiated as a result of an Alert, released by Goddard Space Flight Center, reporting that the resistance of close-tolerance, hermetically sealed Vamistor resistors had increased substantially while operating in space hardware.

The failure investigation included; failure, chemical, metallurgical, and seal leak analyses, failure mechanism studies, and nondestructive stress tests. An addendum to this report will be published at a later date, giving final results, conclusions, and recommendation of continuing tests in process on April 1, 1973. The addendum will provide final analysis of test data recorded for those tests that were completed after this date. Much information concerning studies into the failure mechanism and resistor simulation tests are described in a separate document included as Appendix A of this report.

This investigation has revealed that the increase in resistance is caused by moisture and contaminants entrapped inside the resistor during the manufacturing process. It was also determined that the moisture was probably absorbed from the atmosphere prior to final sealing of the resistors. It is the opinion of personnel, both at the Vamistor Division and at MSFC, that contamination was due to inadequate washing after a copper plating operation.

The test data proves conclusively that the mechanism producing the increased resistance in Vamistor resistors is a reduction in the cross sectional area of the nichrome conductor caused by an electrochemical reaction resulting from a combination of residue from the copper plating solution, water vapor, and the voltage applied across the resistor. All three factors are required to initiate damage to the nichrome conductor.

The nondestructive stress testing has proven that the rate of drift of the resistors decreases with time, and that most drifters show up early in the burn-in, prior to 200 hours. Further testing is in process to formulate concrete conclusions about resistors that become electrically open.

This investigation has shown, also, that it is difficult to analytically define the drift mechanism due to the number of interdependent variables influencing the propensity of each resistor to drift and the subsequent numerous combinations and permutations resulting therefrom.

These parameters are summarized below:

- Moisture content in resistors.
- Quantity and concentration of plating solution.
- Distribution of plating solution within resistor.
- Varying chemical composition of electrolyte within resistor.
- Varying batch size and varying exposure to rinse solution concentration.
- Various voltage gradients within the same resistor size.
- Conductor width and thickness.
- Sealed versus leaking resistor bodies.
- Operational variables of voltage, temperature, and time.

The Vamistor Division, Wagner Electric Corporation, was removed from the Qualified Vendors List (QVL) for MSFC when the Alerts and initial investigation indicated the extent of the failure mechanism. After Vamistor has accomplished the necessary changes and has eliminated this failure mechanism they will be reinstated as a qualified vendor

The conclusions arrived at in this investigation were employed in deciding the course of action to be taken with respect to Skylab hardware containing Vamistor resistors. This course of action is detailed in the Skylab Hardware Vamistor Resistor Survey, Risk Assessment, and Recommendation Report.

INTRODUCTION

This report contains a comprehensive and detailed history of Vamistor resistor failures in NASA hardware and, insofar as possible, in other industrial and military applications of Vamistor resistors; purpose and description of tests performed, with results, conclusions reached, and finally, any recommendations deemed advisable as a result of tests performed and past experience in the use of these resistors in circuitry for equipment in space flight applications.

Equipment malfunctions in NASA hardware were detected by RCA which precipitated Alerts GSFC-72-10 and F8-A-72-01. (Appendix B). The Alerts

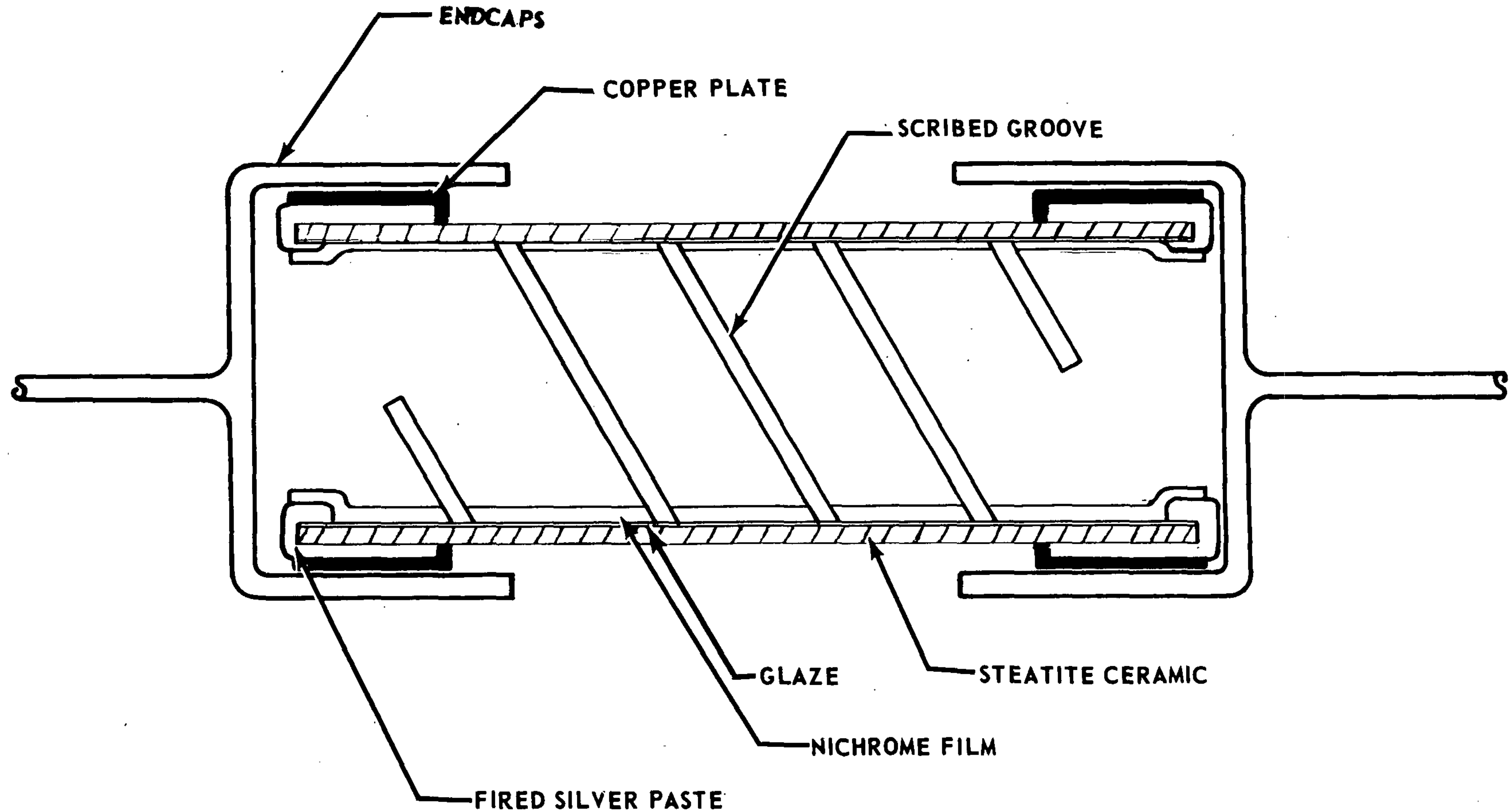
stated that close-tolerance, hermetically sealed Vamistor resistors changed in value (as much as 50 percent) after approximately 200 hours of operation. This resulted in a test program designed to either prove or disprove the suitability of Vamistor resistors (as presently manufactured) for use in Skylab applications. The program was designed to determine the cause of resistance drift of Vamistor resistors used in circuitry in which the resistors were subjected to a low percentage of rated voltage (VR); and to determine the manufacturing process(es) responsible for this deficiency. For MSFC Alerts on Vamistor resistors, see Appendix C.

Because some tests being performed will extend beyond the date of publication, this report will include final results, conclusions, and recommendations based on analysis of test data recorded as of April 1, 1973. An addendum to this report will be published at a later date, in which final test results, conclusions, and recommendations will be provided.

To assist in understanding the purpose of tests performed and the logic of data presented, a description of the physics of the hermetically sealed resistor is beneficial. Basic construction of the hermetically sealed resistor (figure 1) is a hollow, internally glazed, steatite ceramic tube surrounding a Nichrome film resistive element. The Nichrome film (resistive material) is scribed to obtain the required resistance value and to ensure the resistance path. The electrical path for current is from one endcap, through the fired silver paste, to the resistive element and out through the other silver paste, to the endcap on the opposite end. Hermetic sealing is accomplished by solder applied between the copper plate and the endcaps. The entire resistor is encapsulated in epoxy, including the endcaps and Steatite ceramic. The glaze, inside the Steatite ceramic, provides a smooth surface for the Nichrome film.

A description of the process steps for production of the Vamistor resistor is contained in Appendix A.

The Vamistor Division of Wagner Electric Corporation has been cooperative in all phases of this investigation. They have made several trips to MSFC, supplied necessary information and materials to assist in the investigation and attempted to fulfill all requests made of them. Data on the MSFC requested screening of all resistors in their stock, production and screening records, and a list of customers supplied, are examples of information supplied by the Vamistor Division.



NOTE: SOLDER AND EPOXY ENCAPSULANT NOT SHOWN

Figure 1. Physics of Hermetically Sealed Vamistor Resistor

SECTION I CONCLUSIONS

The investigation presented in this report has established, as of 1 April 73, that the Vamistor resistor drift/failure mechanism is an electrochemical process following, in many respects, the classical laws of electrolysis. The basic process involves an electrochemical cell setup in the resistor between a pair of nichrome turns, one serving as the anode and the other as the cathode. The spiral groove, where nichrome has been removed, represents the gap between the electrodes and the conducting medium (or electrolyte) is water, with varying concentrations of the copper sulfate complex. The voltage, when applied across the resistor during operation, provides the driving force for the process. The critical point in the process relating to the failure mechanism is a reduction in area of one or more of the nichrome turns by anodic dissolution. This causes an increase in resistance (or drift). If particular voltage conditions, as well as moisture and plating solution contamination, are present in the resistor in sufficient quantities, the nichrome band, representing the anode, is completely consumed at one point and the resistor electrically opens.

Destructive analyses were performed to determine if the Vamistor resistors contained the moisture and contaminants required to cause this failure mechanism. The result of the mass spectrometer, wet chemical analyses, and microscopic and metallographic examinations were all affirmative. It has been concluded that the determination of the failure mechanism and the ingredients necessary to cause it are valid. Several conclusions were reached from these analyses and examinations as to the content and condition of the resistors; for instance, the resistors contained residual contaminants from the copper plating process in the form of water-soluble salts. These salts increase the ionic conductivity of any moisture present, thus, increasing dissolution of the metal film. The examinations could establish no correlation between the degree of porosity in the ceramic and resistor drift, although, the porosity in the ceramic of all resistors examined was sufficient to provide moisture traps which makes the resistors difficult to dry.

It then became necessary to identify the source of the moisture and contaminants found in the resistors. The results of the tests and investigations performed to identify the source were evaluated closely. It was concluded that even though the Vamistor Division drys all resistors in a vacuum oven, subsequent exposure to the moist, plant air (45 to 65 percent relative humidity) for from 1 hour to several days after drying and prior to sealing, provides sufficient moisture for the electrochemical process. This is based on the fact that an evaporated plating solution absorbed over 3.0 milligrams (mg) of water during three hours exposure to an environment of 100 percent relative humidity. Discussions with personnel of the

Vamistor Division revealed that, in their opinion, varying concentrations of plating solution residue could have been inadvertently left in the resistors as a result of variations in the post plating rinse procedure. The findings of personnel from MSFC, DCASO, and IBM, as stated in their report of the trip to Vamistor Division (Section III, paragraph B), substantiates the opinion that contamination is caused by inadequate cleaning.

The results of the seal leak analyses performed did not indicate any abnormal number of leakers. The seal leak analyses were performed on resistors both from stock and those that had been nondestructive stress tested. A quantity of resistors from stock were seal leak tested and the leakers were subjected to nondestructive stress testing. Also, a quantity of resistors that had been nondestructive stress tested were seal leak tested. Findings from these tests proved that leakers did not necessarily increase in resistance when stress tested and, conversely, resistors that had increased in resistance when stress tested did not necessarily leak.

Nondestructive stress testing (burn-in at X percent VR and Y degrees) was conducted on Vamistor resistors from MSFC stock, NASA space hardware, contractor stock, and on Vamistor resistors produced using the newly installed boiling wash and added rinses. The conclusions reached are as follows:

- The drift rate significantly decreases after approximately 400 hours of testing. This is seen when the test results are evaluated, both with the temperature constant and percent VR variable and, conversely, with temperature variable and percent VR constant.

- The greater percentage of defective resistors can be identified after approximately 200 hours of testing. This is independent of the setting of the defective threshold, i.e., 0.2, 1.0, 5.0 percent, etc.

- The resistance range of 24.9K to 49.9K ohms has demonstrated a higher percentage defective and a greater percentage mean drift than the other resistance ranges tested. However, no resistance values are free from defects.

- The resistance increase is not date code dependent. All date codes tested demonstrated the failure mechanism.

- All resistors that electrically opened demonstrated a substantial amount of drift early in the stress test. However, there are many resistors that have demonstrated a substantial increase in resistance but have not opened.

- Resistors installed in Skylab hardware and those intended for use thereon, demonstrated a resistance increase when subjected to stress testing. Some had drifted while installed in the hardware and some had not; therefore, it was concluded that some Vamistor resistors installed in Skylab hardware were drifting in accordance with the temperature and applied voltage they experienced in the hardware. This initiated extensive circuit analyses of critical hardware and subsequent replacement of some resistors used in critical applications. (See the Skylab Hardware Vamistor Resistor Survey, Risk Assessment and Recommendation Report.)

- Nonhermetically sealed Vamistor resistors do not demonstrate the resistance increase failure mechanism.

- MEPCO and Ward Leonard hermetically sealed resistors do not demonstrate the resistance increase failure mechanism.

- All types of voltages cause the resistors to increase in value; however, the amount and rate of increase varies significantly for each type in the same time period and at the same voltage. The resistance increase in descending order of severity was,

  - dc
  - dc Pulse
  - 60 Hz ac
  - 400 Hz ac

- The results the nondestructive test conducted on the Vamister resistors produced, using the new wash technique, tend to indicate that the new procedures are not sufficient to eliminate the drift problem. The results of tests conducted on the new resistors, which passed the newly installed Vamistor screening (8 hours burn-in at 20 to 30 percent VR and at ambient temperature with a 0.5 percent drift reject criteria), indicate that this screening is ineffective in detecting some drifters. Both of these tests are continuing and will be included in the final report.

- When the effect of the applied voltage is evaluated for all temperatures employed in the stress tests the following order of severity is attained:

  - 20 to 30 percent VR
  - 50 to 70 percent VR
  - 15 percent VR
  - 80 to 110 percent VR
  - 10 percent VR

- 5 percent VR
- 0.1 percent VR
- 1.0 percent VR

The mean percent drift and percent defectives for the 0.1, 1.0, and 5 percent VR are much less in order of magnitude than are 10 percent VR and above.

- When the effect of temperature is evaluated for all applied voltages employed in the stress tests the following order of severity is attained:

  - Plus 25 degrees C
  - Plus 5 degrees C
  - Minus 20 degrees C
  - Plus 50 degrees C
  - Plus 125 degrees C
  - Plus 100 degrees C
  - Plus 75 degrees C

The mean percent drift and percent defectives for the 50, 75, 100, and 125 degrees C are much less in order of magnitude than are -20, 5, and 25 degrees C.

As stated above, the rate and amount of drift varies with the type voltage applied. This drift also varies with the magnitude of applied voltage. The insensitivity of the resistors to drift at low voltages (< 10 percent VR) is consistent with the presence of a decomposition potential for the electrolyte, below which the electrochemical process is very slow. On the basis of the electrolytic cell studies (presented in Appendix A) this voltage, in the range of 1.5 to 1.7 volts, appears to be insensitive to electrolyte concentration or electrode separation over a wide range. Once the decomposition potential has been exceeded, the cell current for a given voltage increases appreciably with higher plating concentrations and decreasing electrode separation.

The dramatic decrease in cell resistance changes, through the voltage range of the decomposition potential, is again emphasized by the time-to-failure studies. In the area of 1.5 to 2.0 volts, the time required for the cell to electrically open by complete anode dissolution dropped exponentially, but the 1.25 vdc cell has been operating continuously for 1000 hours with no significant anode dissolution.

The stabilization of the drifting resistors (or tendency toward lower drift rates) is believed to be a complex function of water depletion by electrolysis, with attendant variations in decomposition potential due to initial confining pressures inside the resistor, and the change in the width of the nichrome band as a function of the electrochemical action.

SECTION II. RECOMMENDATIONS

Any further usage of metal film, hermetically sealed Vamistor resistors should be premised on a complete investigation of the manufacturing processes to ensure that moisture is eliminated from the resistors and that a positive cleaning operation is verified, prior to sealing, to eliminate all contaminants.

A revision in the test program in MIL-R-55182 would be appropriate. The revised test program should include resistance drift testing at low power levels and over an extended period of time. It is recommended that these tests be conducted at 25 percent of rated voltage and ambient temperature for 200 hours with a 0.2 percent drift reject criteria.

Current usage of the Vamistor resistor should be assessed to determine whether or not the resistor meets application requirements. This evaluation should give consideration as to the criticality of application, redundancy, power levels, period of "on" time, etc..

SECTION III. FAILURE HISTORY

A. SUMMARY OF VAMISTOR RESISTOR FAILURES

1. Apollo Telescope Mount (ATM) Signal Conditioner Printed Wiring (PW) Assembly. A 124k ohm, one percent Vamistor resistor (Type RNR55C), Date Code 7016C, failed in the ATM signal conditioner PW assembly, Part Number 50M12749-1. The PW assembly monitors the rate gyro. This failure occurred prior to issuance of Alerts described in paragraph 2 of this section. The failure mode consisted of an increase of resistance from a nominal 124k to 216k ohms after measurement calibration procedure was performed. It was reported that during the period of resistance change the voltage being applied to the rate gyro measurement system was ± 45 vdc, and that environmental temperatures ranged between +25 and +45 degrees centigrade (C). The failed resistor was received at the Construction Analysis Laboratory, MSFC, where the following analysis was performed to determine the cause of failure.

a. Resistance Measurement. The resistance, measured with an ohmmeter, was 260k ohms.

b. Seal Leak Test and Radiographic Examination. A seal leak test and radiographic examination of the failed resistor revealed no anomalies.

c. Surface Examination and Epoxy Removal. The surface of the failed resistor was examined in detail for indications that cracks might have progressed to the inner Nichrome helical metal film element and caused the increase in resistance. Since this examination revealed no defects, the epoxy was removed with "Strip Solve 741," after which the resistor was remeasured to verify that the measured resistance value remained at 260k ohms.

d. Induced Solder Reflow. The endcaps of the failed resistor were heated to induce a deliberate solder reflow while the resistance was measured across them. During this operation, the resistance momentarily measured the nominal resistance of 124k ohms, after which an open circuit was indicated.

e. Visual Inspection of Metal Film. The endcaps were removed to permit visual examination of the metal film within the ceramic cylinder. Many of the helixes were deficient, almost to the point of discontinuity. Much of the Nichrome was missing, although the silver termination beneath the Nichrome was still present. The results of this examination were documented and photographs were taken.

f. Examination of Other Vamistor Resistors. Five additional Vamistor resistors pulled from MSFC stock were examined to determine if deficiencies noted in the failed resistor were present. The five resistors were subjected to similar examinations given to the failed resistor and no anomalies were found. Film deficiencies noted in the failed resistor were not present in the five resistors examined.

g. Recommendations. As a result of the findings of this analysis, it was recommended that no further action be taken unless other resistors from the same lot as the subject device showed evidence of deviation. It must be noted again that this failure and analysis occurred prior to the failure and issuance of Alerts described in the following paragraph.

2. Earth Resources Technology Satellite (ERTS) Tape Recorder. Alerts GSFC-72-10 and F8-A-72-01 reported that Vamistor resistor part Number RNR55C1332FP, manufactured by Vamistor Division of Wagner Electric Corporation, Cedar Knolls, N.J., caused a malfunction in the ERTS Tape Recorder. The resistance value had increased by approximately 50 percent from nominal after 200 hours of operation in circuitry of the ERTS tape recorder. This resistor and another failed Vamistor resistor, which measured well above the nominal resistance of 13,300 ohms, were returned to RCA, Central Engineering, for a failure analysis. An analysis of these two Vamistor resistors revealed the following:

a. The cause of the high positive change in resistances was due to migration of the metal film resistance element, thus reducing the resistance path and correspondingly increasing resistance.

b. The above phenomenon occurs if the resistive element becomes contaminated.

c. High resistance values (5k to 10k ohms and up) are more susceptible to this failure mechanism than are low resistance values (10 to 100 ohms).

NOTE: The above findings are those of RCA and do not necessarily concur with MSFC findings presented in this report. Refer to Appendix B for Alerts GSFC-72-10 and F8-A-72-01.

3. Prototype Star Tracker. The Navigation and Control Division of Bendix Aerospace Electronics Company, Teterboro, New Jersey, has experienced Vamistor failures in three ATM Star Tracker photomultiplier tubes, Part Number 2125590, used in Star Tracker system Serial Number 4 on the prototype vehicle. Failures were traced to Vamistor resistors in the voltage divider networks. The part numbers of all resistors that failed are RNR60C. The failure of one tube was attributed to one open resistor and five resistors that shifted in resistance beyond the allowable specification requirement, all of Lot Date Code 7031 (table 1). The second tube failure had one open resistor and one resistor that shifted in value, both of Lot Date Code 7141. The third tube failure was due to two resistors of Lot Date Code 7023 shifting in resistance beyond the allowable specification requirement. The first two tubes failed after 34 hours of operation, and the third tube had 1180 hours before the problem manifested.

4. Multiple Docking Adapter (MDA) Signal Conditioner. A flight mode MDA signal conditioner with more than 1100 hours of operating time failed and was subjected to disassembly. The Vamistor resistors were measured at Martin Marietta Co. (MMC), Denver, Colo., and eight exceeded the specified 1.0 percent tolerance, the greatest deviation from nominal resistance being 3.7 percent (table 2). A total of 66 Vamistor resistors (type RNR55C) were removed from the MDA signal conditioner and subjected to nondestructive stress testing at 25 percent VR. After 158 hours of testing, 16 resistors had drifted greater than 0.05 percent. Eight resistors were out of tolerance when removed and continued to drift even further when measured after 65 hours and again after 158 hours of testing. Eight resistors, within specified tolerance prior to testing, showed drift when measured after 65 hours of testing. All out of tolerance resistors were Lot Date Code 7028.

5. ATM Signal Conditioning Racks. Seven measurements on flight ATM signal conditioning racks drifted out of tolerance limits of applicable specification. Two racks were returned to MSFC to determine cause of drift. It was verified that drift was due to out-of-tolerance Vamistor resistors.

6. Workshop Computer Interface Unit (WCIU) and ATM Digital Computer (ATMDC). A total of 254 Vamistor resistors were removed from the WCIU and ATMDC after the Vamistor drift problem was discovered. WCIU Serial Number 1 had 144 Vamistors removed and Serial Number 3 had 81; ATMDC, Serial Number 4 had 29 Vamistors removed. Of the total checked, 16 Vamistors measured outside design tolerance limits of applicable specification (table 3). The maximum deviation from design tolerance was a 3.88k ohm, 0.1 percent resistor which

Table 1. Prototype Star Tracker Analysis

Type	Ohms	Lot Date Code	% From Nominal (Approx.)	Operating Time (Hours)	Application Stress (VRDC)*	Analysis
RNR60C	499K	7023	20	1180	0.36	None
RNR60C	499K	7023	33	1180	0.36	None
RNR60C	499K	7031	Open	34	0.36	Cut Open, destroyed by arcing
RNR60C	499K	7031	4	34	0.36	None
RNR60C	499K	7031	1.2	34	0.36	None
RNR60C	499K	7031	27.5	34	0.36	Cross-Sectioned; element eroded
RNR60C	499K	7031	3.2	34	0.36	None
RNR60C	499K	7031	5.6	34	0.36	None
RNR60C	499K	7141	Open	34	0.36	None
RNR60C	499K	7141	1.8	34	0.36	None

* VRDC = Rated DC Voltage

Table 2. MDA Signal Conditioner Analysis and Burn-In Test

Type	Ohms	Lot Date Code	Initial % From Nominal	Pre-Burn-In Operating Hours	Pre-Burn-In Operating Stress	% Drift After 65 Hours	% Drift After 158 Hours	Analysis
RESISTORS OUT OF TOLERANCE WHEN REMOVED								
RNR55C	3320	7028	1.5	1111	0.22	0.06	0.09	Test Continues
	3320	7028	2.3	1111	0.22	0.06	0.12	Test Continues
	4220	7028	1.2	1111	0.05	0.42	1.00	Test Continues
	3320	7028	1.2	1111	0.22	0.03	0.06	Test Continues
	1820	7028	1.04	1111	0.06	0.21	0.10	Test Continues
	3320	7028	3.7	1111	0.22	0.03	0.15	Test Continues
	3320	7028	3.3	1111	0.22	0.06	0.15	Test Continues
	3320	7028	2.5	1111	0.22	0.06	0.18	Test Continues
RESISTORS WITHIN TOLERANCE WHEN REMOVED								
RNR55C	1820	7028	OK	1111	0.06	0.05	0.05	Test Continues
	1820	7028	OK	1111	0.06	0.05	0.10	Test Continues
	1820	7028	OK	1111	0.06	2.5	3.4	Test Continues
	4220	7028	OK	1111	0.05	0.04	0.11	Test Continues
	1820	7028	OK	1111	0.06	0.16	0.43	Test Continues
	4220	7028	OK	1111	0.05	0.05	0.12	Test Continues
	1820	7028	OK	1111	0.05	0.22	0.38	Test Continues
	1820	7028	OK	1111	0.06	0.11	0.38	Test Continues

Table 3. WCIU and ATMDC Resistors Failure Analysis

Type	Ohms	Lot Date Code	% Drift From Design Tolerance	Operating Time (Hours)	Application Stress (% VRDC)
RNR55C	3.88K	7019	+0.04	2860	10-14
	3.88K	7019	0.29	2860	10-14
	3.88K	7019	0.13	2860	10-14
	4.02K	7021	0.03	2860	10-14
	3.88K	7019	0.21	2860	10-14
	3.88K	7019	0.90	458	10-14
RNR60E	5.11K	7019	0.06	2860	0.1-0.9
	2.94K	7015	0.61	2860	15-19
	5.11K	7017	0.04	2860	0.1-0.9
	5.11K	7017	0.03	2860	1-4
	5.11K	7017	0.04	5720	1-4
	5.11K	7017	0.01	5720	1-4
	5.11K	7017	0.04	458	1-4
	5.11K	7017	0.07	915	1-4
	5.11K	7017	0.02	915	1-4
	10K	7016	0.36	783	20-38

NOTES:

1. VRDC = Rated DC Voltage
2. All resistors have a 0.1% design tolerance except 10K resistors which have 1.0%.
3. No drifters exceeded minimum allowable ΔR (13.6%) and none caused hardware failure.

measured approximately one percent over design tolerance. This resistor had operated for 458 hours in WCIU Serial Number 3 at 10 to 14 percent rated dc voltage and a temperature of approximately 31 degrees C. None of the resistors exceeded the minimum allowable 13.6 percent change in resistance for digital subsystem failure. There is no correlation between percentage drift and operating hours. See Section IV, paragraph B.2.c for tests performed on the 254 resistors removed from this hardware.

7. Inverter/Lighting Control Assembly (I/LCA). A qualification model I/LCA that had successfully passed all tests was disassembled by MMC, Denver, Colo., for testing of Vamistor resistors after the Vamistor drift problem was discovered. The assembly contained 115 Vamistor resistors, of which six were found to exceed the tolerance limits of the applicable specification. The greatest drift from nominal resistance was a 12.1k ohm resistor, Lot Date Code 7051 (table 4); measured resistance was 7.5 percent of nominal after 400 hours of operation. There are 313 resistors in the flight I/LCA. There is no way of determining how many are Vamistors other than by opening the box and inspecting where possible. A total of 590 were pulled from the QUAL I/LCA and 115 were Vamistors. It cannot be assumed that the same number are on the flight unit.

B. REPORT OF TRIP TO VAMISTOR DIVISION

1. Purpose of Trip. A group of quality and reliability assurance (Q&RA) and materials personnel from MSFC, Defense Contracts Administration Services Office (DCASO), and International Business Machines (IBM) visited The Vamistor Division of Wagner Electric Corporation, Cedar Knolls, N.J. The purpose of the visit was to perform a survey in order to assess the capability of the Vamistor Division to produce a quality metal film resistor, and to determine what areas of their manufacturing process may have been responsible for the resistor failures currently experienced by MSFC. During the visit, particular emphasis was placed on assessing their processing and inspection criteria. A thorough inspection of every processing step for the resistor was accomplished by the visiting group. In addition, samples were collected at each significant process step for further analysis in Huntsville.

2. Cause of Resistor Metal Film Contamination. The metal migration that occurs at reduced voltage over a period of time is largely attributed both to the presence of residual salts and moisture. Personnel at the Vamistor Division instituted an extra cleaning step in July of 1972. It is believed that this step has reduced incidence of resistor failure; however, inadequate protection from moisture and salts entrapment still prevails. The following findings and recommendations by the visiting group were reported:

Table 4. I/LCA Qualification Unit Resistors Failure Analysis

Type	Ohms	Lot Date Code	% Drift From Nominal	Operating Time		Drift Hours	Analysis
				Hours	Stress		
RNR55C	12,100	7051	7.5	400	69%	Burn-in not started	None
RNR55C	4,990	7143	1.1	400	14%	Burn-in not started	None
RNR70C	4,640	7136	1.4	400	58%	Burn-in not started	None
RNR70C	4,640	7136	3.0	400	58%	Burn-in not started	None
RNR55C	12,100	7143	2.5	400	69%	Burn-in not started	None
RNR55C	12,100	7052	5.5	400	69%	Burn-in not started	None

NOTE: QUAL I/LCA contains 115 Vamistors. All other resistors were within tolerance.

a. Interim Storage During Processing. The resistors (less endcaps) are vacuum baked then placed in open aluminum trays awaiting next assembly process. During this interim storage, the resistor body and endcaps are subject to the ambient environment for a period ranging from 1 hour to several days. No further cleaning is accomplished prior to the next step in assembly, where the body of the resistor and the two endcaps are pressed together.

b. Inadequate Cleaning Process. The cleaning process, just prior to the vacuum bake operation, lacks the necessary controls for consistent and effective cleaning of the resistor body. The deionized water and alcohol rinse solutions are only changed every 2 hours, regardless of the number of pieces processed.

c. Inadequate Metal Film Cutting Process Control. The metal film cutting (spiraling) process needs to be controlled so that the cutting tool does not penetrate through the underlying glaze. If this glaze were cut through, the porous ceramic cylinder could allow moisture to enter the metal film area.

d. Process Procedures and Inspection Criteria Not Definitive. Overall, the documented process procedures and inspection criteria are not very definitive. In addition, the quality control (QC) organization is grossly inadequate to perform the required surveillance necessary for producing quality resistors. For example, the above became evident while reviewing electrical screening data taken during low voltage (1/5 VRDC) burn-in. This screening was initiated in October of 1972 on 100 percent of the hermetically sealed resistors. Some 22,000 resistors with 42 rejections were documented; a rejection consisting of a delta resistance shift greater than 0.05 percent. In reviewing the recorded data, showing resistance change, a number of errors were detected. The QC manager stated that the burn-in was conducted by production personnel and he had no explanation for the errors.

e. Conclusions and Recommendations to Vamistor Division Management. The visiting team members agreed that the present product from the Vamistor Division is not of sufficient quality for space flight application. This conclusion is based, primarily, upon the apparent need for better process controls at the Vamistor Division. The following recommendations were given verbally to Vamistor Division management on December 15, 1972.

(1) Better Cleaning Controls. The deonized water and alcohol rinse solutions used for cleaning resistors, prior to vacuum bake, are not adequately controlled. A conductivity meter (or equivalent) should be utilized in order to determine the condition of the above rinse solution. Appropriate contamination cutoff points should be established and the controls documented.

(2) In-Process Storage Environment. The vacuum bake operation should be followed by an inert gas (or equivalent) storage environment until the resistor body and the two endcaps are assembled. Preferably, this assembly should be accomplished in an inert atmosphere, such as a glove box. Also, the resistor caps should be vacuum baked to preclude moisture entrapment. The above process would prevent moisture and reduce particulate contamination within the resistor cavity.

(3) Better Control of Metal Film Cutting Process. The metal film cutting process should have better controls to prevent complete penetration of the glaze by the cutting tool.

f. Additional Space Available. The company has leased additional space adjacent to their present operation. This could afford an excellent opportunity for incorporating the suggestions outlined in paragraph e above.

C. NASA, DOD, AND INDUSTRY VAMISTOR USAGE SURVEY

1. Review of Experience Data on Vamistor Resistors. Queries were directed across a large segment of NASA, Department of Defense (DOD), and industry as to usage and experience data on Vamistor resistors. The review included data from vendors reported by Vamistor Division as having procured their resistors as well as data from other users. To date, response from these sources generally indicate that they either do not use hermetically sealed resistors or have experienced no problems; however, the following problems (in addition to those in paragraph A of this section)have been reported:

a. John Fluke Manufacturing Company. The John Fluke Manufacturing Company, Seattle, Washington, (a manufacturer of precision test equipment) purchased 4.5 megohm, 2 watt resistors from Vamistor in 1970. Requirements of military specifications were not imposed. As a result of equipment problems involving Vamistor resistors, their stock of resistors were tested for 24 hours, after which most

resistors had either increased in resistance beyond the percentage tolerance or had opened completely. Vamistor informed them that the problem was due to contamination of water used to clean the resistors and that they had resolved this problem. Vamistor was unable, however, to supply John Fluke Company with a sufficient quantity of good resistors to meet their schedules. Consequently, this company no longer orders resistors from Vamistor but purchases from Electra, Pyrofilm, and International Resistor Company. The John Fluke Company uses both hermetically and nonhermetically sealed resistors in their equipment.

b. General Microwave Corporation. General Microwave Corporation, Farmingdale, N. Y., purchased approximately 300 resistors from Vamistor in the last 2 years. These resistors were purchased to MIL-R-55182 Specifications. They experienced one system failure due to Vamistor resistance drift. The company was unable to supply information as to percentage of rated voltage applied or hours of operation.

c. Airborne Instruments Laboratory. Airborne Instruments Laboratory, Deer Park, N.Y., purchased approximately 200 Vamistor resistors to MIL-R-55182 in the past 2 years. These resistors are used in automatic ground equipment. Vamistor resistors in their systems operate at less than 50 percent VR; no test time was available. Two failures due to resistance drift occurred in their equipment. After receipt of the Alerts, Vamistor resistors in stock were tested and found to be defective. They do not plan to use Vamistor resistors in the future.

d. Honeywell Incorporated. Honeywell, Incorporated, St. Petersburg, Florida, purchased Vamistor resistors in the past 2 years for use in hardware manufactured to United States Air Force specifications. After receipt of the Alerts, a purge of their stock of Vamistor resistors revealed that approximately half of their stock was out of tolerance. Some of the out-of-tolerance resistors found in stock are of a later date code than those mentioned in the MSFC Alert. Honeywell is preparing another Alert on findings from their tests.

e. Sperry Marine. Sperry Marine Division, Charlottesville, Va., procured one small lot of Vamistor resistors which they had not put into use. After receipt of the Alerts, tests were conducted per Alert recommendations and resistances were found to be higher than specified. Sperry plans to purchase lots of later date codes from Vamistor.

f. General Electric. General Electric, Valley Forge, Pa., purchased approximately 500 resistors from the Vamistor Division for the ERTS program. Three failures occurred in 1971; two resistors drifted out-of-tolerance and one failed open. These resistors were rated at 125 milliwatt (mw) and used at 2 mw. The problem was thought to be lot oriented.

g. Raytheon. Raytheon, N. Dighton, Mass., had the original problem in the hardware built for RCA. Raytheon is presently collecting test data to forward to MSFC.

2. Matrix of Experience Data on Vamistor Resistors. A matrix which summarizes the information received from the contractors, centers, and agencies contacted is shown in table 5. A matrix which delineates the responses of the contractor government agencies contacted is presented in table 6.

D. SUMMARY OF RNR RESISTORS RECEIVED BY MSFC FROM 1968 TO 1972

Table 7 shows the total number of Vamistor, MEPCO, and Ward Leonard resistors submitted to MSFC receiving inspection for acceptance between 1968 and 1972. The table also shows the correlation between the total parts rejected and the defect mode that caused the rejections.

E. FAILURE HISTORY OF ASSEMBLIES HAVING TYPE RNR RESISTORS

Nonconformance Reports (NR's) written against 278 assemblies having circuitry using Type RNR resistors were reviewed for functional failures, cause of the failures, and to determine if the functional failures might be related to the Vamistor resistor problem. This review was accomplished using a computer printout, listing all NR's on the ATM and all Skylab hardware at MSFC. In addition, Discrepancy Reports (DR's) on the ATM [while at Manned Space Flight Center (MSC) and Kennedy Space Center (KSC)] and NR's on Government Furnished Equipment (GFE) were reviewed. Table 8 gives a listing of those assemblies reviewed that should be considered suspect of having Vamistor resistor problems. Further investigation by Astrionics has been conducted into these failures.

Table 5. Experience Data-Vamistor Hermetically Sealed Resistors

Agency/Contractor	Number Contacted	No Response	Data Not Avail-able	Not Used	Used No Problem	Used Problem	Remarks
Major MSFC contractors	12			6	3	3	Bendix, Martin and IBM
Other NASA centers	7		2		4	1	GSFC (RCA)
DOD Agencies	4		2		2		
Vamistor Corporation customers	70	3	2	27	32	6	Sperry Marine, Airborne Instr, Lab, Honeywell, General Microwave, John Fluke, and Raytheon
Miscellaneous	2			1		1	G. E., Valley Forge, Penn.
TOTAL	95	3	6	34	41	11	

Table 6. *Experience Data-Vendors Utilizing Vamistor Resistors*
(Sheet 1 of 17)

AGENCY / VENDOR	Hermetically Sealed Resistors (Thin Film) Used	Project	When Procured/ Installed	Acceptance Test Run Time/% Rated Voltage	System Test Run Time/% Rated Voltage	Problems Experienced
IBM Owego, NY & Huntsville, Alabama	RNR YES MIL-R-55182	ATM	1970-1972		458-5,720 hrs	No system failures, Vamistor resistors removed from system and tested from 0.1 to 70% VR-did experience drift. Detailed reports already presented.
MMC Denver, Co.	RNR YES MIL-R-55182	MDA				No system failures. Resistors removed from signal conditioners and ILCA tested from 5% - 69% VR- did show some drift. Detailed report already presented.
Bendix Teterboro, NJ	RNR YES MIL-R-55182	ATM			34 - 1,180 hrs. on S/N 4 Startracker 36% VR	Eight resistors failed in S/N 4 Star Tracker during systems tests. Detailed report already presented.
Airborne Instruments (AIL) Deer Park, N. Y.	Approx. 200	Auto. Ground Equipment	Over last 2 yrs.	No test time	No test time. Operate at less than 50% rated voltage.	Two known Vamistor ΔR failures. Testing to MSFC Alert identified defective Vamistors in

Table 6. Experience Data-Vendors Utilizing Vamistor Resistors (Sheet 2 of 17)

Agency / Vendor	Hermetically Sealed Resistors (Thin Film) Used	Project	When Procured/ Installed	Acceptance Test Run Time/% Rated Voltage	System Test Run Time/% Rated Voltage	Problems Experienced
Airborne (Continued)						stock. 50 procured for current program will not be used.
Bell Aerospace Buffalo, N. Y.	YES	Viking				No known problems in critical applications.
Farrand Optical, Valhalla, N. Y.	NO					
General Microwave Corp., Farmingdale N. Y.	RNR/RNC YES MIL-R-55182	Gov't. contractors	200 to 300 in last 2 years.	Info. unavailable	Info. unavailable	In 2 yrs.: 1 field failure (similar to present problem); 1 temperature cycling failure (determined to be improper application of conformal coating).
Metermod Instrument Corp., Long Island City, N. Y.	RNR/RNC YES MIL-R-55182	Not available	Unknown	Unknown	Unknown	No problems.

Table 6. Experience Data-Vendors Utilizing Vamistor Resistors (Sheet 3 of 17)

AGENCY / VENDOR	Hermetically Sealed Resistors (Thin Film) Used	Project	When Procured/ Installed	Acceptance Test Run Time/% Rated Voltage	System Test Run Time/% Rated Voltage	Problems Experienced
Grumman Aerospace, Hicksville, N. Y.	RNR/RNC YES MIL-R-55182	Various	Unknown film resistors purchased from various suppliers.	Unknown	Unknown	No problems have been reported on various projects for this type of resistor.
Spaceonics, Inc., Madison, Ala.	NO					
Dynamics Corp. of America, Boynton Beach, Florida	NO					
Merrick Scales, Passaic, N. J.	NO					
Artisan Electric, Parsippany N. J.	NO					

Table 6. Experience Data-Vendors Utilizing Vamistor Resistors
(Sheet 4 of 17)

Agency / Vendor	Hermetically Sealed Resistors (Thin Film) Used	Project	When Procured/ Installed	Acceptance Test Run Time/% Rated Voltage	System Test Run Time/% Rated Voltage	Problems Experienced
RCA, Burlington, Mass.	RNRXXC&E YES	Various for Navy USAF Army	N/A	N/A	N/A	Most programs in a prototype State and these problems not seen as yet
MIT, Lexington, Mass.	NO					
Vought Aeronautics, (LTV) Dallas, Tex.	RNRXXC&E YES	Unknown	Unknown	None	Less than 50% VR	None
MDAC, St. Charles, Mo.	RNR60C YES MIL-R-55182	AM Spartan	1972 Unknown	Unknown Unknown	None yet installed on AM hardware. Unknown	 No problems to date.
MDAC, St. Louis, Mo.	RNR YES MIL-R 55182	AM Spartan	Unknown Purchased from several vendors, cannot tell which are Vamistor - some definitely are.	Unknown	Approx. 20,000 hrs. on AM - 10-30% of rated voltage. On the average approximately 1,800,000 hours on Spartan.	No failures due to change of resistance on AM. No system failures on Spartan, 5 rec. insp. rejects for wrong resistance value.

Table 6. Experience Data-Vendors Utilizing Vamistor Resistors (Sheet 5 of 17)

AGENCY / VENDOR	Hermetically Sealed Resistors (Thin Film) Used	Project	When Procured/ Installed	Acceptance Test Run Time/% Rated Voltage	System Test Run Time/% Rated Voltage	Problems Experienced
Hazeltine Corp., Huntington, N. Y.	RNR/RNC YES MIL-R-55182					Mr. Warner, QA Mgr., does not think these resistors are used in present designs (may be for spares of older designs). Will call back if he can locate failure/usage information. Has Alerts and is cognizant of the problem.
Lockheed Electronics, Plainfield, N. J.	NO					
North American Rockwell, Columbus, Ohio	RNR/RNC YES MIL-R-55182					Not used in Condor project per Jim Braun. He has Alerts on problem. Will call if NAR-C has significant information on other project usage/failures.
G. E., Huntsville Ala.	RNR YES MIL-R-55182	Saturn ESE	1970-1971	Unknown	Unknown	No known problems.

Table 6. Experience Data-Vendors Utilizing Vamistor Resistors (Sheet 6 of 17)

Agency / Vendor	Hermetically Sealed Resistors (Thin Film) Used	Project	When Procured/ Installed	Acceptance Test Run Time/% Rated Voltage	System Test Run Time/% Rated Voltage	Problems Experienced
Bendix N. Hollywood, CA	RNR YES MIL-R-55182	Unknown	1972 approx. 7,000 resistors	Unknown	400-500 hrs. at less than 2% VR	No known failures.
Westinghouse Astro Nuclear Lab., Pittsburgh, Penn.	RNR YES MIL-R-55182	Skylab	Unknown	Unknown	Unknown	Vamistor used on M518 and M512. No known problem on equipment. No extensive testing on resistors.
ITT, Gilfillan, Van Nuys, Calif.	YES	Navigational Computer	Unknown	Unknown	Unknown	Have not been used in past. RNR types are being included in new design.
General Dynamics, Pomona, CA	NO					
Honeywell Inc., West Covina, California	NO					

Table 6. Experience Data-Vendors Utilizing Vamistor Resistors (Sheet 7 of 17)

AGENCY / VENDOR	Hermetically Sealed Resistors (Thin Film) Used	Project	When Procured/ Installed	Acceptance Test Run Time/% Rated Voltage	System Test Run Time/% Rated Voltage	Problems Experienced
G.E., Erie, Penn	NO					
Boeing Wichita, Kansas	NO					
Adirondack Radio Supply, Amsterdam, N.J.	NO					
Collins Radio, Cedar Rapids, Iowa	NO					
Westing-house Research Lab., Pittsburgh, Penn. & other divs	NO					

Table 6. Experience Data-Vendors Utilizing Vamistor Resistors (Sheet 8 of 17)

AGENCY / VENDOR	Hermetically Sealed Resistors (Thin Film) Used	Project	When Procured/ Installed	Acceptance Test Run Time/% Rated Voltage	System Test Run Time/% Rated Voltage	Problems Experienced
Lear Siegler, Grand Rapids, Mich.	NO					
Nucor, Danville, N. J.	YES		Past 5 yrs.	Not available	Not available	Several hundred used, no problems.
Litton System, College Park, MD	YES					No problems. Very few used.
Applied Devices, College Point, NY	YES					No problems. Very few used.
Western Electric, Aurora, IL	YES					No problems. Very few used.
Vought Missile & Space, Warren, MI						No problems. Very few used.

Table 6. Experience Data-Vendors Utilizing Vamistor Resistors (Sheet 9 of 17)

AGENCY / VENDOR	Hermetically Sealed Resistors (Thin Film) Used	Project	When Procured/ Installed	Acceptance Test Run Time/% Rated Voltage	System Test Run Time/% Rated Voltage	Problems Experienced
Litton Systems, Woodland Hills, CA	NO					
Sperry Marine Div., Charlottes-Ville, VA	YES	N/A	1 small lot recently procured.			Tested per Alert recommendations resistance higher than specified. Plans to purchase further lots from Vamistor of later date codes.
Union Carbide Corp., Oak Ridge, TN	YES	Various				No problems experienced.
Philco Ford Corp., Palo Alto, CA	YES	ATS SMS				No problems.
Northrup Corp., Norwood, MA	YES		Small lot purchased			None of those purchased have yet been tested or used in any equipment.

Table 6. Experience Data-Vendors Utilizing Vamistor Resistors (Sheet 10 of 17)

AGENCY / VENDOR	Hermetically Sealed Resistors (Thin Film) Used	Project	When Procured/ Installed	Acceptance Test Run Time/% Rated Voltage	System Test Run Time/% Rated Voltage	Problems Experienced
Honeywell Radiation Ctr., Lexington, MA	YES		Small lot purchased for lab use.			None of those purchased have yet been tested or used in any equipment.
John Fluke Mfg. Co., Seattle, Washington	RNR YES	Unknown	1970	N/A	Time unknown at 1/9 W, resistors are 2W, 4.5 megohms.	Problems in equipment due to resistance change. Purge of stock revealed majority of resistors increased in resistance or showed open after 24 hrs. Company no longer buys from Vamistor.
Honeywell Inc., Seattle, Washington	NO					
Honeywell, Inc., St. Peterburg, Florida	RNRXXC's YES	USAF contracts	1969-72	None	Less than 50%	Purge to stock after receipt of Alerts revealed approx. half Vamistor resistors in stock were bad. Some were of later date code than in MSFC Alert.

Table 6. Experience Data-Vendors Utilizing Vamistor Resistors (Sheet 11 of 17)

Agency / Vendor	Hermetically Sealed Resistors (Thin Film) Used	Project	When Procured/ Installed	Acceptance Test Run Time/% Rated Voltage	System Test Run Time/% Rated Voltage	Problems Experienced
Honeywell Inc. (Continued)						Will issue their own Alert.
Weston, Archbold, Penn.	NO					
Sperry Gyroscope, Great Neck, N. Y.	NO					
North Altantic Industries, Plainview, N. Y.	RNR YES MIL-R-55182	Potted Modules (Analog)	Procured 6/16/72 & 10/9/72	Less than 50%	Unknown	Only one failure in these modules, however, it was attributed to misuse and, therefore, appears unrelated to resistor problems.
Lockheed, Burbank, Calif.	YES	Avionics for P-3, S-3 and L1011				No problems.

Table 6. Experience Data -Vendors Utilizing Vamistor Resistors (Sheet 12 of 17)

AGENCY / VENDOR	Hermetically Sealed Resistors (Thin Film) Used	Project	When Procured/ Installed	Acceptance Test Run Time/% Rated Voltage	System Test Run Time/% Rated Voltage	Problems Experienced
Dana Labs., Inc., Irvine, Calif.	NO					
Zenith Radio, Chicago, IL	NO					
ITT, Avionics Nuttley, N. J.	NO					
ITT Defense Comm. Clifton, N. J.	RNRXXC&E YES RNRXXG	Navy Systems	1972	Unknown	In use for past 6 mos. - % VR not known.	No problems known.
G. E., Liverpool, N. Y.	RNC 70 YES MIL-R-55182	SUS 26 Sonar				No problems.
Boeing, Seattle, Washington	RNR YES MIL-R-55182	SRAM	1972	Approx. 50 hrs. at less than 50% VR	Unknown	No failures to date.

Table 6. **Experience Data-Vendors Utilizing Vamistor Resistors**
(Sheet 13 of 17)

AGENCY / VENDOR	Hermetically Sealed Resistors (Thin Film) Used	Project	When Procured/ Installed	Acceptance Test Run Time/% Rated Voltage	System Test Run Time/% Rated Voltage	Problems Experienced
Boeing Kent, Washington	RNR YES MIL-R-55182	LRV	1970-1971	Unknown	Less than 200 hrs. on LRV-% VR Unknown.	No known problems.
Narda Microwave, Melville, NY						Would not supply info on the telephone.
Hughes Aircraft Co., Los Angeles, Calif.	NO					
Hughes Aircraft Co., Tucson, Ariz.	NO					
Teledyne Ryan Aeronautics, San Diego, CA	NO					

Table 6. Experience Data-Vendors Utilizing Vamistor Resistors (Sheet 14 of 17)

AGENCY / VENDOR	Hermetically Sealed Resistors (Thin Film) Used	Project	When Procured/ Installed	Acceptance Test Run Time/% Rated Voltage	System Test Run Time/% Rated Voltage	Problems Experienced
Langley						Data not available.
Goddard	YES	ATS				Issued Alert GSFC 72-10.
MSC	YES	Apollo				No problems.
KSC	YES	Saturn				No problems.
Army-MICOM						Data not available.
Army-Safeguard						Data not available.
Rocketdyne	NO					
TRW/ Redondo Beach	NO					
CCSD/ Michoud	NO					
Boeing/ Michoud	NO					

Table 6. Experience Data-Vendors Utilizing Vamistor Resistors
(Sheet 15 of 17)

Agency / Vendor	Hermetically Sealed Resistors (Thin Film) Used	Project	When Procured/ Installed	Acceptance Test Run Time/% Rated Voltage	System Test Run Time/% Rated Voltage	Problems Experienced
G. E., Valley Forge, PA	YES	ERTS	Past 2 yrs. approx. 500		125 mw rated, used at 2 mw.	3 failures - 2 drifted from 80-100% rated value, 1 failed open. Thought to be lot oriented.
Navy	YES	Poseidon				No problems.
Air Force	YES					No problems.
MDAC-WD	NO					
Transistor Devices, Cedar Knolls, NJ	NO					
Narda Microwave, Plainview, NY						Would not supply info. on the telephone.
Bendix/ Ann Arbor	YES	ALSEP				No problems.
NR/Seal Beach and Downey	NO					

Table 6. Experience Data-Vendors Utilizing Vamistor Resistors (Sheet 16 of 17)

AGENCY / VENDOR	Hermetically Sealed Resistors (Thin Film) Used	Project	When Procured/ Installed	Acceptance Test Run Time/% Rated Voltage	System Test Run Time/% Rated Voltage	Problems Experienced
NR / Autonetics	NO					
Ames	YES					No problems.
LRC	YES	Titan				No problems.
JPL						Data not available.
Hazeltine, Greenlawn, NY	YES					No problems.
Bendix, Mishawaka, Ind.	NO					1200 procured by mistake-returned to Vamistor for credit.
Sentinel Electronics Philadelphia, Pa.	YES-Not to MIL-R-55182					No problems - purchased to Ordnance drawings which require more burn-in than MIL Spec.
Sanders, Nashua, NH	YES					Small quantity purchased for lab use. No usage data available. No problems.

Table 6. Experience Data -Vendors Utilizing Vamistor Resistors (Sheet 17 of 17)

AGENCY / VENDOR	Hermetically Sealed Resistors (Thin Film) Used	Project	When Procured/ Installed	Acceptance Test Run Time/% Rated Voltage	System Test Run Time/% Rated Voltage	Problems Experienced
Sanders, Bedford, Mass.	YES					Small quantity purchased for lab use. No usage data available. No problems.
Raytheon, Waltham, Mass.	YES					Small quantity purchased for lab use. No usage data available. No problems.
Raytheon, N. Dighton, Mass.	YES					Originally discovered problem in hardware built for RCA.

Table 7. Summary of MSFC Receiving Inspection of Type RNR Resistors from 1968 to 1972

		Vamistor	MEPCO	Ward Leonard	Total
	Total Parts Received	47,119	130,266	10,387	187,772
	Total Parts Rejected	2,446	1,714	1,887	6,047
	Percent Rejected	5.19	1.32	18.17	3.22
	DEFECT MODE				
A.	Improperly Packaged	57	118***	1,782	1,957
B.	Improperly Identified	1,101*	183	26**	1,310
C.	Documentation Missing or Inadequate	771*	1,239***	72	2,082
D.	Poor Workmanship	3	80	0	83
E.	Failed to Meet Mechanical Specification	517	109	9**	635
F.	Failed to Meet Electrical Specification	80	22	0	82
G.	Physically Damaged	2	3	0	5
H.	Contamination	0	0	0	0

* 65 resistors had two discrepancies reported

** 2 resistors had two discrepancies reported

*** 40 resistors had two discrepancies reported

Table 8. MSFC Hardware that is Suspect of Having Previous Vamistor Resistor Problems.

Part Number	Part Name	Suspect Functional Failures
40M26550	ECS Inverter Assy.	4
40M38391-7	PW Assy. Timer	4
40M38439-1	PW Board Assy.	8
40M38872	Power Supply Assy.	2
40M38998-1	PQ Assy. Pwr. Monitor	1
50M12724	Signal Cond. Rack	11
50M12729	LLL Camera Assy.	2
50M12730	LLL TV Camera System	1
50M12745	PW Assy. (Range Card)	6
50M12747-13	PW Assy. Positive V	1
50M13188	H-Alpha Camera Assy.	2
50M16033	X-ray Event Analyzer	3
50M16129	TCS Monitor	1
50M16371	Assy. Cont. Cir. & Pwr.	1
50M17067	Metabolic Analyzer	2
50M22145	Star Tracker	3
50M22146	Star Tracker Electronics	1
50M38500	Exp. Pointing Electronics	3
95M10001	M-512 Chamber Assy.	1
95M10460-1	PW Assy. (Power Supply)	1
95M10464-1	PW Assy. Ampl.	2
95M10606-1	PW Assy. M8886	2

SECTION IV. TEST PROGRAM

A. FAILURE INVESTIGATION

1. Failure Mechanism Investigation. The following investigation on failure mechanism was conducted:

a. Determination of Failure Mechanism. For information on determination of failure mechanism refer to Section V, of Materials Division Vamistor Resistor Report (Appendix A of this report). For detailed results of a series of studies on nichrome electrolytic cells, performed to aid in understanding the nature of the electrochemical process causing the failure mechanism, See Section IV of Appendix A.

b. Effect of Environment on Failure Mechanism. A test was performed on two 1/8-watt resistor blanks, with endcaps installed on the cathode end of the resistors, to determine effects of plating salt residues versus no residues. One blank was contaminated with plating solution and allowed to dry. At the beginning of the test, both resistors measured 7.2k ohms. They were then placed in a corrosion jar with distilled water in the bottom of the jar (not in contact with parts). Approximately 100 percent relative humidity was created in the corrosion jar by heating water with a heat lamp and bubbling dry nitrogen (N_2) through the water. A voltage of 6.7 vdc was applied to the resistors for 2 hours, then they were removed from the jar for resistance measurements. The contaminated resistor had increased to 11k ohms and the other remained at 7.2k ohms. The resistors were returned to the jar for 2 additional hours and the resistance was measured again. The contaminated resistor was open, and the other measured 4.7k ohms, but resistance continued to increase during measurement.

The cause of the decrease in resistance of the uncontaminated resistor was not explained at this time because it did not appear to be significant to a definition of the failure mechanism. The results of this test indicate that resistance drift does not occur in resistors exposed to high humidity for a short time when plating salts are absent. When gross amounts of plating salts are present, drift appears to be catastrophic.

While cleaning resistor blanks in the lab (using ultrasonics) it was noted that air was trapped in a 1/10-watt resistor blank and could not be forced out. This observation substantiates the ineffectiveness of the original cleaning technique used at the Vamistor Division plant to remove residual plating salts.

Laboratory testing was conducted to ascertain if the environment (including assembly simulation) was a contributing factor to resistor failures. Specifically, the following environmental tests were performed:

(1) Inert environment - argon and fluorocarbon fluid absorption medium FC43

(2) Assembly and processing with a vorite conformal coat during which a vacuum de-air was applied.

(3) Assembly as in (2) above, but without vacuum

(4) Free Air

(5) Vacuum

The result of this testing produced no statistically significant differences between the various environments. It is concluded, therefore, that neither the normal manufacturing steps (or operations) nor the environments tested have an effect on the failure mechanism.

For further information on the effect of environment on failure mechanism refer to Section V, of the Materials Division Vamistor Resistor Report (Appendix A of this report).

c. Effect of Operating Parameters on Failure Mechanism. Resistor blanks obtained from the Vamistor Division were used to duplicate the failure mechanism. A 1/4-watt spiraled blank was cut in half with a laser. Silver paint was used to connect the spirals in series and tungsten probes were used to contact each end of the resistor. Measured resistance of the resulting resistor was 1940 ohms. A voltage of 5 vdc was then applied (approximately 33 percent VR) and several drops of tap water were added. Within seconds, the nichrome film started decomposing from the edge of the spiral nearest the anode. After 2 to 3 minutes, a powdery deposit and gas bubbles were noted at the cathode end of the resistor. The process was found to occur on the other end when the polarity was reversed. This test was repeated using one-half of a 1/2-watt resistor and identical results were obtained.

For further information on effect of operating parameters on failure mechanism See Section V, of Materials Division Vamistor Resistor Report (Appendix A of this report).

2. Destructive Analyses. The following destructive analyses and examinations were performed on Vamistor resistors.

a. Mass Spectrometer Analysis. The gaseous materials from the internal volume of the resistors were analyzed by placing each one in a small, vacuum tight fixture. This fixture was then evacuated to 10^{-6} torr to remove atmospheric gases from the fixture and external resistor surface. Internal gases may also be removed if the resistor seal leaks at 10^{-6} torr. After evacuation and a determination of the background spectrum of fixture and resistor, the resistor was broken by driving a sealed shaft against the

resistor body. The gases contained in the resistor expanded into the inlet sample chamber and the total pressure was measured. Because of the small internal volume of these resistors, very few gave a measurable total pressure on the micromanometer gauge. The constituent mass and abundance (peak height) were recorded for each resistor and corrected for background masses.

Qualitative evaluation of the spectra verified atmospheric constituents (nitrogen, oxygen, and water) present within the resistors. Quantitative evaluation of peak heights is rather complex and involves three primary factors:

(1) Total pressure (peak height is directly proportional to pressure)

(2) Partial pressure (partial pressure of each constituent determines effusion rate of its molecules through the gold-leak)

(3) Ionization efficiency of each constituent (ionization is required to separate and detect the masses).

Comparison standards would eliminate most of the problems encountered in quantitative analyses; however, these were not available for this evaluation.

Because of the aforementioned factors, the peak height from each resistor was normalized to eliminate total pressure influences. Consequently, the data obtained reflect peak height percentages which are comparable between resistors but are not true element or compound percentages. Because the primary objective was to determine differences between good and bad resistors, this technique does, however, provide a method of comparison.

The results of the mass spectrometer analyses are given in table 9 for 51 resistors which had been subjected to burn-in and for 14 resistors from MSFC stock. No helium was found in any of the resistors analyzed. It is significant that some moisture (H_20) was found in all but five resistors (both good and bad); however, the mere presence of H_20 in a resistor does not necessarily mean that the resistor will become bad. The H_20 must have access to the metal film in order to cause a resistance increase under the burn-in conditions and, conversely, the absence of water in a bad resistor may be the result of its being consumed in the hydrolysis of the metal film.

NOTE: Hereafter the resistors that are referred to as "good" are those which had less than 0.2 percent change in electrical resistance after burn-in and those referred to as "bad" had more than 0.2 percent change. Resistors referred to as "stock" had not been subjected to the burn-in.

For more information on findings of the mass spectrometer analyses, refer to Section III of Materials Division Vamistor Report (Appendix A of this report).

Table (9). Results of Mass Spectrograph Analyses of Vamistor Resistors Subjected to Burn-In and from MSFC Stock

Date Code	Value, K Ohms	Moisture Content, Percent of Ion Current					
		Resistors Subjected to Burn-In				MSFC Stock	
		Good		Bad			
		Min.	Max.	Min.	Max.	Min.	Max.
7014C	20	0	46.3(4)				
7052C	10			18.7	68.8(10)		
7141C	4.99	0	40.9(2)		19.0(1)		
7141C	20		14.7(1)		21.1(1)		
7240C	47.5					7.6	41.7(14)
7234C	12	25.8	27.4(2)				
7234C	19.1	12.4	32.9(2)		10.5(1)		
7234C	4.99	0	40.9(3)		19.0(1)		
7234C	16.9				23.2(1)		
7234C	27.4	42.9	46.0(2)		29.4(1)		
7234C	3.01		1.2(1)				
7234C	24.9		22.6(1)				
7235C	21	6.1	15.0(2)		11.7(1)		
7235C	22.9	5.4	11.7(2)		0(1)		
7235C	39.2	0	5.8(2)				
7234C	100			4.8	34.1(4)		
7235C	20			4.8	17.4(2)		
7235C	22.1				4.3(1)		
7235C	24				12.4(1)		
7235C	34			2.7	12.3(2)		

NOTE: The number enclosed in parenthesis is the number of resistors in the sample.

b. Wet Chemical Analysis. The following wet chemical analyses were performed on Vamistor resistors:

(1) An analysis was performed on 22 Vamistor resistors that had been removed from WCIU serial numbers one, three, and four. These resistors were divided into sample lots of 11 good and 11 potentially bad resistors (for purposes of analysis) and subjected to seal leak tests. For results of seal leak tests see paragraph A.3.c. in this section. The resistors were then cleaned and circumferentially scribed with a laser. Two resistors from each sample were opened in a laminar flow bench, visually inspected, and all were found to contain residues. All resistors in each sample were opened and the samples were washed in a small quantity of distilled water (in two separate containers) to force any residue into the solution. The two sample solutions were analyzed separately for SO_3/SO_4, NH_3, Cu, Cl, Ni, and Cr. The SO_3/SO_4 analysis was positive (approximately 10 to 15 parts per million (ppm)), using barium sulfate precipitate test for both samples. Precipitate tests were negative for Cl. Atomic absorption revealed presence of Cu (10 to 12 ppm) in both samples and did not detect any Cr or Ni. This confirmed the suspicion that plating residues were present in the resistors; however, no significant difference was noted between the two samples.

(2) After analysis by mass spectrograph, 52 fractured resistors (26 good and 26 bad) were analyzed in groups, separately, for water soluble salts. Distilled water was added to each set of resistors, the water was heated, and an analysis was performed on the water extract. The results of the analysis are presented in table 10 showing the elements and ions found in each set of resistors. The most significant findings were that sulfate and sulfide ions were present in the bad resistors, but not in the good, indicating lack of complete rinsing of the resistors after the copper plating operation. Since iron was found, an iron analysis was performed on the water soluble extract from resistor lead wires and was verified to be positive. Iron was also verified by atomic absorption analysis.

(3) For more information on wet chemical analyses refer to Section III, Paragraph B. of Materials Division Vamistor Resistor Report (Appendix A).

c. Microscopic and Metallographic Examination. The resistors evaluated by microscopic and metallographic examination are listed in table 11. The significant findings of each resistor are included.

Some resistors were cut open by slicing longitudinally with a diamond saw while others were mounted intact in epoxy for metallographic examination.

Table (10). Results of Wet Chemical Analyses of Vamistor Resistors for Water Soluble Salts

Element/Ion	Bad Resistors	Good Resistors
	Series 1 (8 ea.)	
	7235C	7234C
Ammonia	Positive	Positive (Weak)
Sulfate	Positive (Weak)	Negative
Sulfide	Positive	Negative
Copper	Negative	Negative
Chromium	Negative	Negative
Iron	Positive	Positive
Silver	Negative	Negative
Nickel	Negative	Negative
	Series 2 (8 ea.)	
	7234C	7235C
Ammonia	Positive (Weak)	Negative
Sulfate	Positive (Weak)	Negative
Sulfide	Positive	Negative
Copper	Negative	Negative
Chromium	Negative	Negative
Iron	Positive	Positive
Silver	Negative	Negative
Nickel	Negative	Negative
	* Series 3 (10 ea.)	
Sulfate	Positive (Weak)	Negative
Sulfide	Positive	Negative

*Date Code not identified

Table 11. Results of Microscopic and Metallographic Evaluation of Resistors Subjected to Burn-In and From MSFC Stock Evaluated for Workmanship and Resistive Film Conditions (Sheet 1 of 2)

S/N	Date Code	Value, K Ohms	Conditions	Significant Findings
68(R)	7112C	40.2	Bad	Metal Film Edges Grossly Irregular.
191(W)	7234C	24.9	Good	Porosity in Ceramic and Epoxy Coat (Transverse Cross-Section).
219(W)	7234C	19.1	Bad	Metal Film Edges Moderately Irregular, Separation of Solder Bond to Cu/Ag at Endcaps.
220(W)	7234C	19.1	Good	Metal Film Edges Slightly Irregular. Less than Average Porosity in Ceramic.
221(W)	7234C	19.1	Good	Separation of Solder Bond to Cu/Ag at Endcaps. Less than Average Porosity in Ceramic.
230(W)	7234C	12.0	Good	Examined by SEM. No Significant Findings.
231(W)	7234C	12.0	Good	Spot of Contamination or Corrosion on Metal Film. SEM Analysis Attempted but not Successful.
222(R)	7234C	4.32	Good	Porosity in Ceramic Less Than Average.
58(R)	7235C	20.0	Bad	Porosity in Ceramic Less Than Average.
206(R)	7235C	100	Bad	Metal Film With Uneven Thickness and Irregular Edges at Cuts.
125(W)	7235C	34.0	Bad	Average Porosity in Ceramic. Gross Irregularity of Film Edge at One Area.
215(W)	7235C	22.1	Bad	Average Porosity in Ceramic.
131(W)	7112C	37.4	Good	Uneven Coverage of Silver on Ends of Ceramic Tubing.

Table 11. Results of Microscopic and Metallographic Evaluation of Resistors Subjected to Burn-In and From MSFC Stock Evaluated for Workmanship and Resistive Film Conditions (Sheet 2 of 2)

S/N	Date Code	Value, K Ohms	Conditions	Significant Findings
135(W)	7112C	37.4	Bad	Uneven Coverage of Silver on Ends of Ceramic Tubing.
132(W)	7224C	6.81	Bad	Grossly Irregular Film at Cut.
139(W)	7224C	6.81	Bad	Irregular Film Edge, Spot on Film.
35(W)	7032	301	Bad	Resistor "Open" - Gross Erosion of Film.
31(W)	7031	301	Bad	Resistor "Open" - Gross Erosion of Film.
31(R)	7234C	5.05	Stock	Separation Between Cu and Solder at End Cap. Film Edge Slightly Irregular.
32(R)	7234C	5.05	Stock	None
33(R)	7234C	5.05	Stock	None
34(R)	7234C	5.05	Stock	Voids in Silver Coat.
35(R)	7234C	5.05	Stock	Voids in Silver Coat.
36(R)	7234C	5.05	Stock	Metal Film Edge Irregular.
37(R)	7234C	5.05	Stock	Separation Between Solder and Cu/Ag Beneath End Cap at One End.
38(R)	7234C	5.05	Stock	Voids in Silver Coat at One End.
39(R)	7234C	5.05	Stock	None
40(R)	7234C	5.05	Stock	Voids in Silver Coat at One End.

Figure 2 shows a good resistor, S/N 231, cut open to expose the metal film with spiral cut on the inner diameter of the ceramic tube. Photo 1 is an optical view and photo 2 is viewed with a scanning electron microscope (SEM). These photos illustrate some construction features of these resistors.

(1) Evaluation of Endcap Seal. Resistors cross sectioned to determine condition of the endcap seal are shown in figures 3 through 6. The silver applied to ends of the ceramic tube was generally of non-uniform coverage and displayed voids, particularly at the edge of the inner diameter (see figures 3 and 4). No failures could be attributed to this but it does indicate a lack of controls for the silvering process. The poor coverage could also allow moisture to penetrate into the pores of the ceramic where it would be difficult to remove during subsequent drying operations. The copper plating applied to the silver is shown on resistor S/N 125 in figure 5. The plating covers the silver on the outer diameter of the tube and extends to approximately one-half of the tube wall. A suspected defective hermetic seal of a bad resistor, S/N 219, is shown in figure 6. The solder has voids and is separated from the silver. Also evident is separation of the copper overplate from the silver. The use of a copper plate to improve solderability of the silver is of dubious value, because any mechanism/material which would hinder a metallurgical bond of solder to silver (a readily solderable material) would tend to prevent bonding of the copper plating to the silver as well. In this case the presence of the glass frit in the silver (used to bond the silver to ceramic by "firing") would reduce the solderability of silver and also, adherence of the copper plate.

(2) Evaluation of Porosity of Ceramic. The porosity of the ceramic (Steatite) tube was evaluated to determine if a correlation could be established between degree of porosity (number and size of pores) and condition of resistor (good or bad). Three resistors of each condition were cross sectioned in longitudinal or transverse directions to the resistor axis and photomicrographs were taken at the same magnification (100X) of the ceramic tube. As shown in figure 7, there is no apparent correlation between the two factors. For example,good resistor S/N 191 (photo 3) has as much or more porosity as bad resistor S/N 125 (photo 2); however, it can be assured, logically, that a resistor with greater porosity would hold or trap more moisture and cause a greater drift than one with less porosity, other circumstances being equal. The amount of moisture retained would also depend, to some extent, on the degree of interconnected porosity that allows moisture to permeate the ceramic.

(3) Evaluation of Ni-Cr Metal Film. The metal film was examined both with optical microscope and metallograph. The film on both good and bad resistors was normally reflective and of uniform appearance. The edges of the spiral cut in the film in good resistors were more or less regular; however, the bad resistors had film edges which varied from slightly to grossly irregular. Some typical examples comparing the varying degrees of irregularity are shown in figure 8. The initiation of the

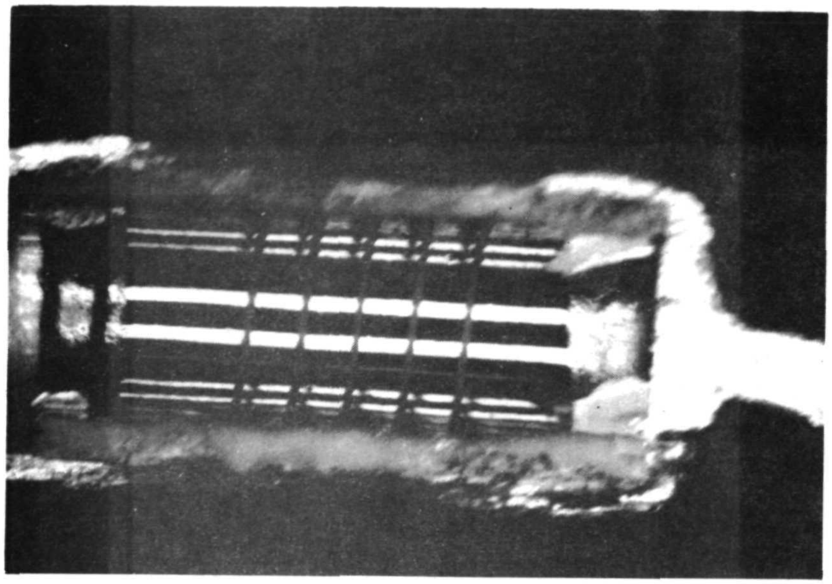


Photo 1: 15X Optical View of Resistor Interior (Horizontal Bright Lines are Light Reflections)

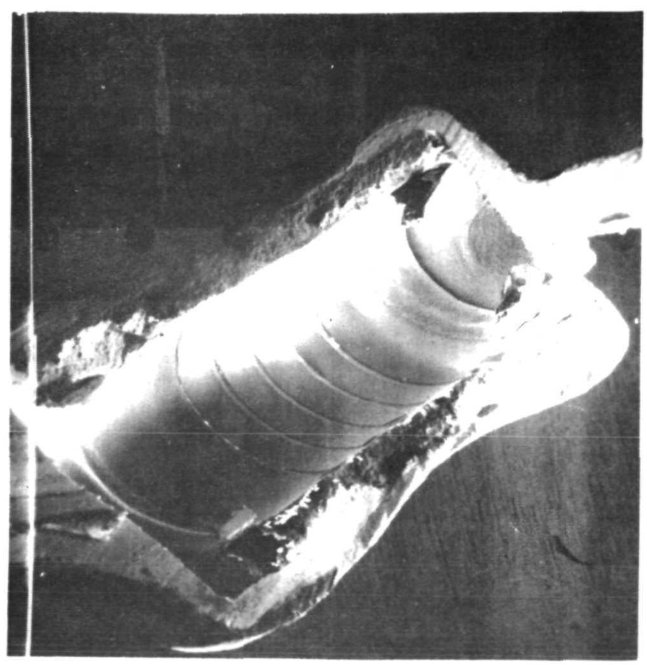
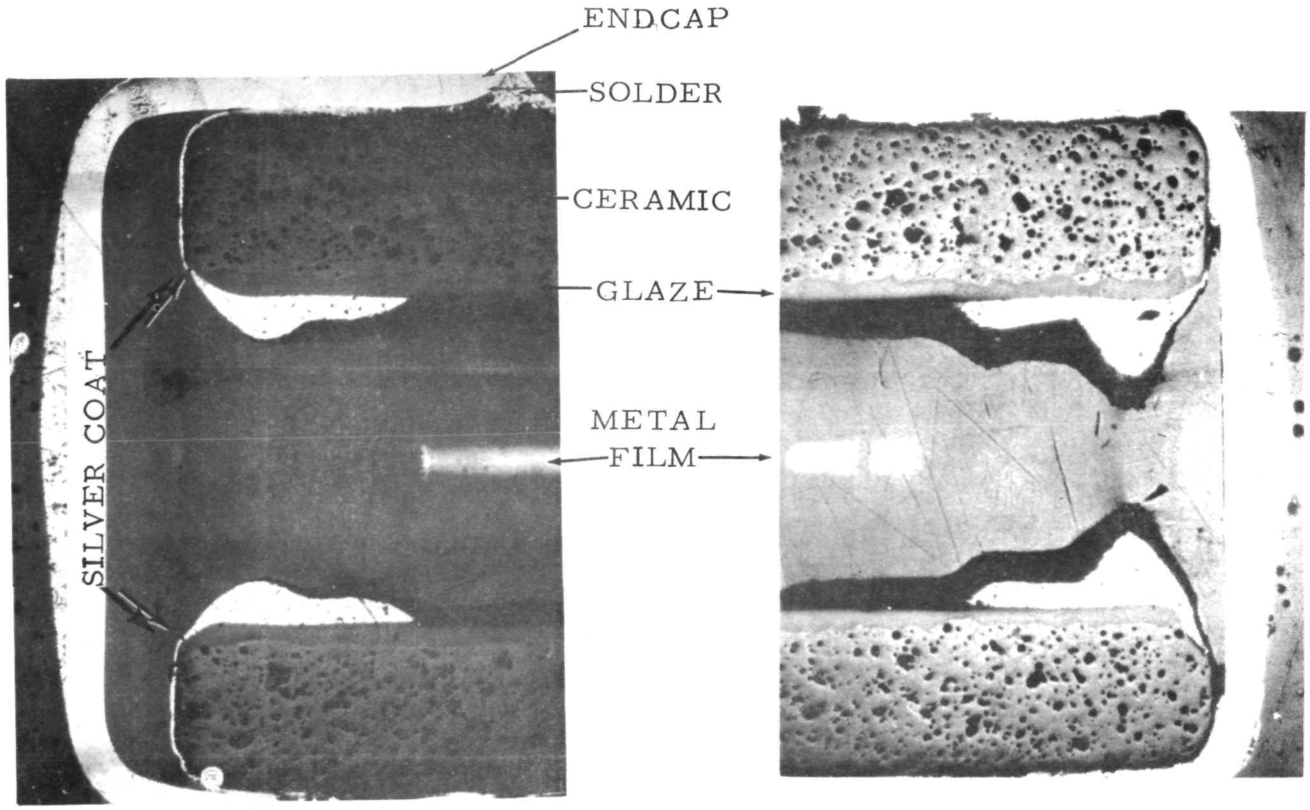


Photo 2: 16X SEM View (Light Areas Due to Static Charge Buildup)

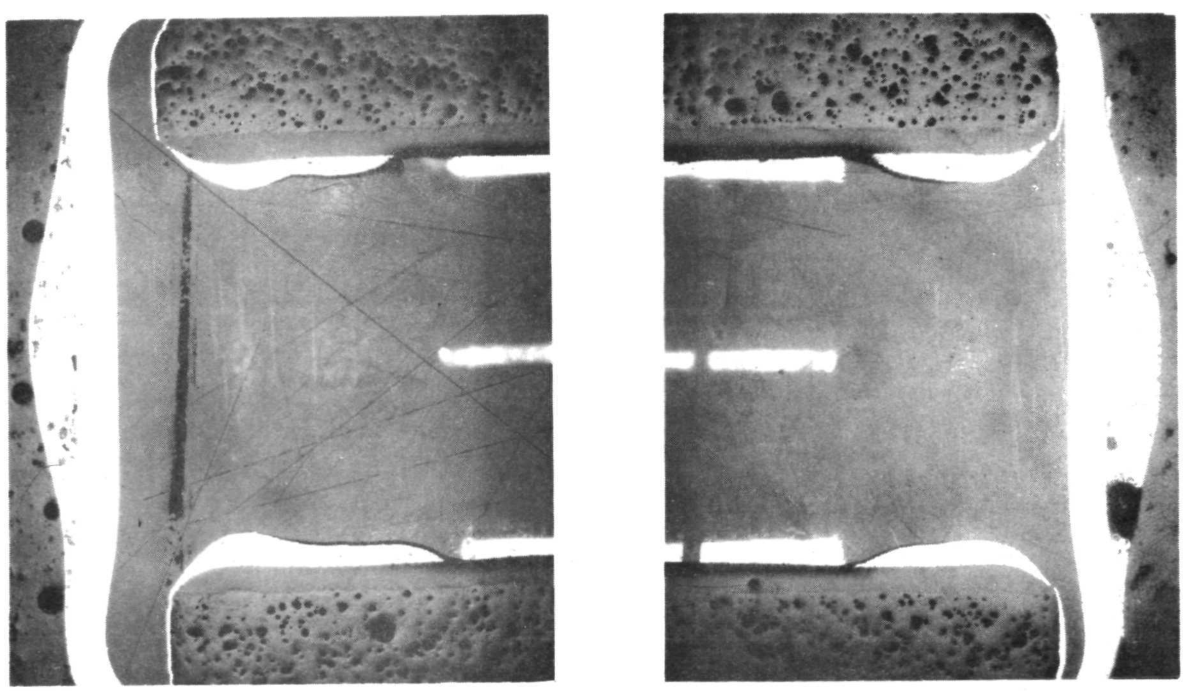
NOTE: Shows metal film with spiral cuts.

Figure 2. Photographs of Good Resistor, S/N 231.



NOTE: Arrows point to thin silver coating on end of tube.

Photo 1: 35X Good Resistor S/N 131



NOTE: Shows condition of silver coating similar to Photo 1.

Photo 2: 35X Bad Resistor S/N 135

NOTE: Porosity of ceramic is similar in both resistors.

Figure 3. Cross Section of End Cap Regions of Good and Bad Resistors.

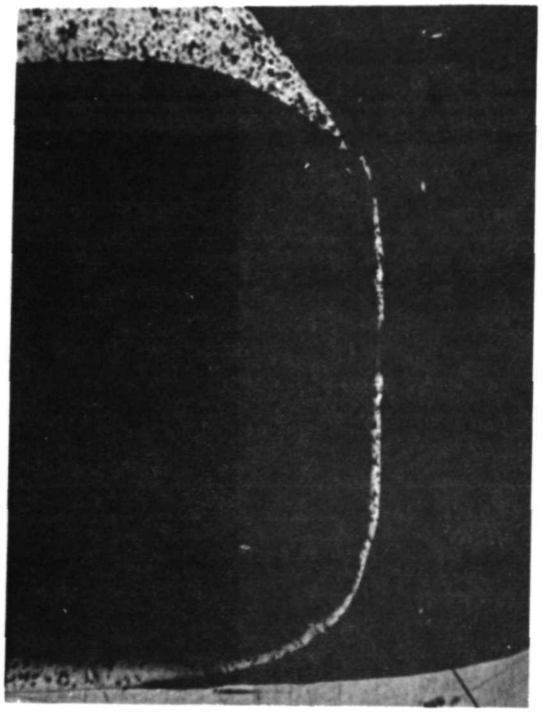


Photo 1: 150X

Photo 2: 1000X

NOTE: Illustrates uneven thickness and voided condition of silver coat.

Figure 4. Photomicrographs of Resistor S/N 131.

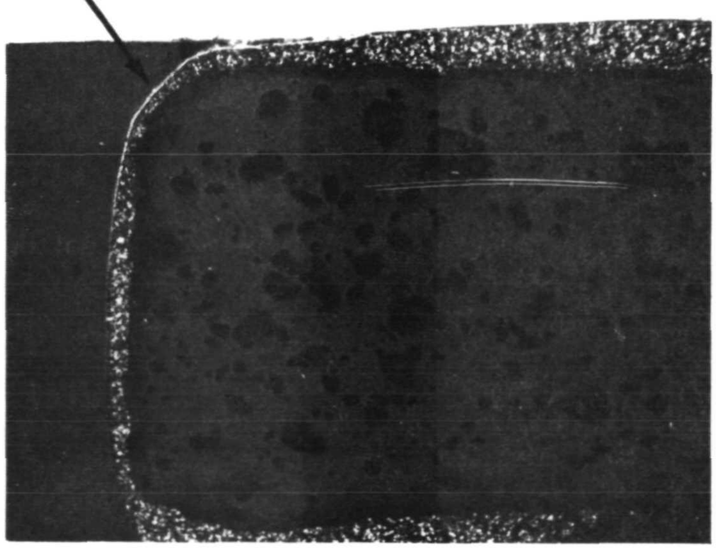


Figure 5. Copper Plating Over Silver on Ceramic Tube End of Resistor S/N 125 (Etched) 100X

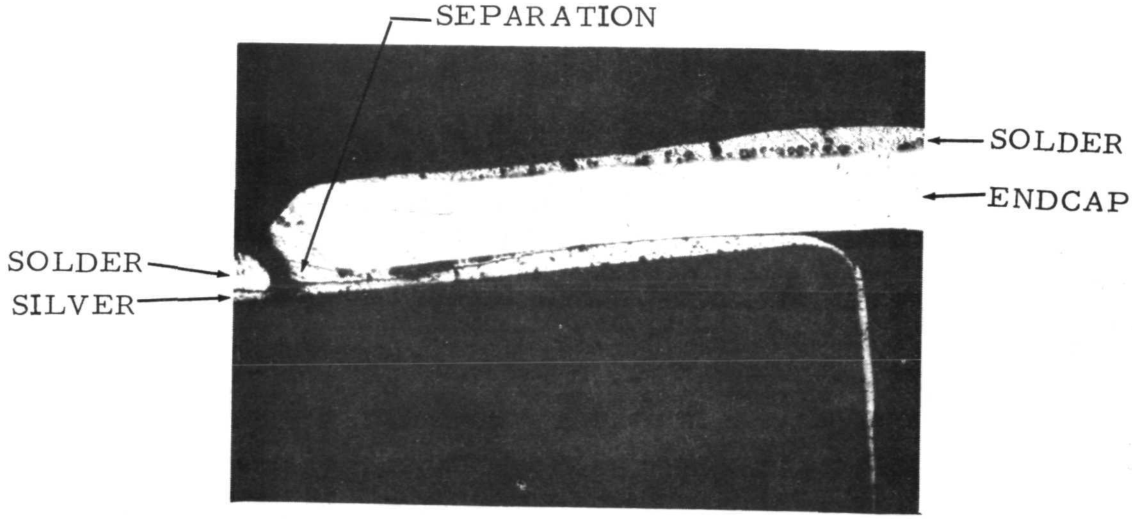


Photo 1: 75X Overall View

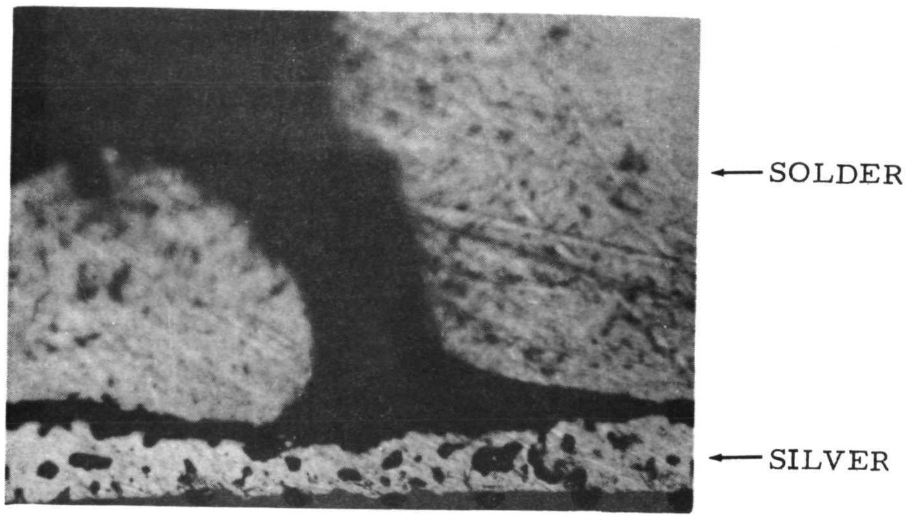


Photo 2: 500X Void in Solder and Separation (Arrow, Photo 1)

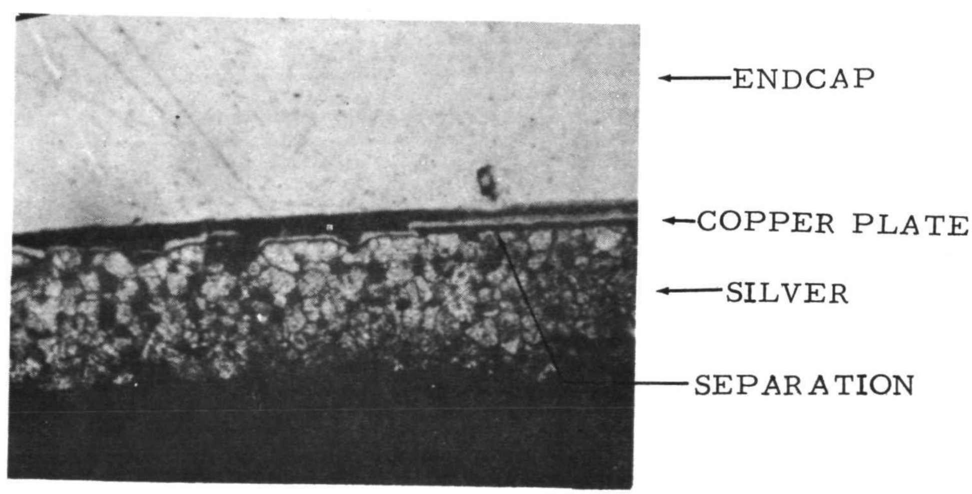


Photo 3: 500X Copper Plating Separation from Silver

NOTE: Photos show separation of solder and copper and void in solder fillet.

Figure 6. Endcap seal of Bad Resistor, S/N 219.

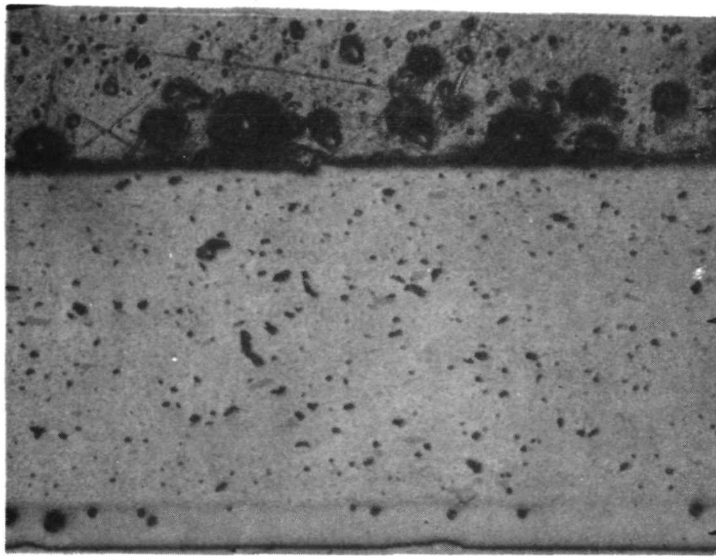


Photo 1: Longitudinal Cross Section of Good Resistor S/N 220

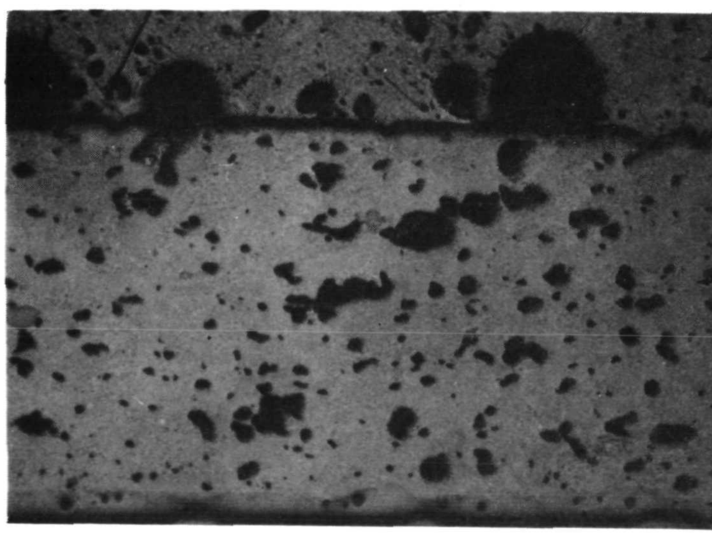


Photo 2: Longitudinal Cross Section of Bad Resistor S/N 125

Figure 7. Comparison of Porosity of Good and Bad Resistors, (100X) (Sheet 1 of 2)

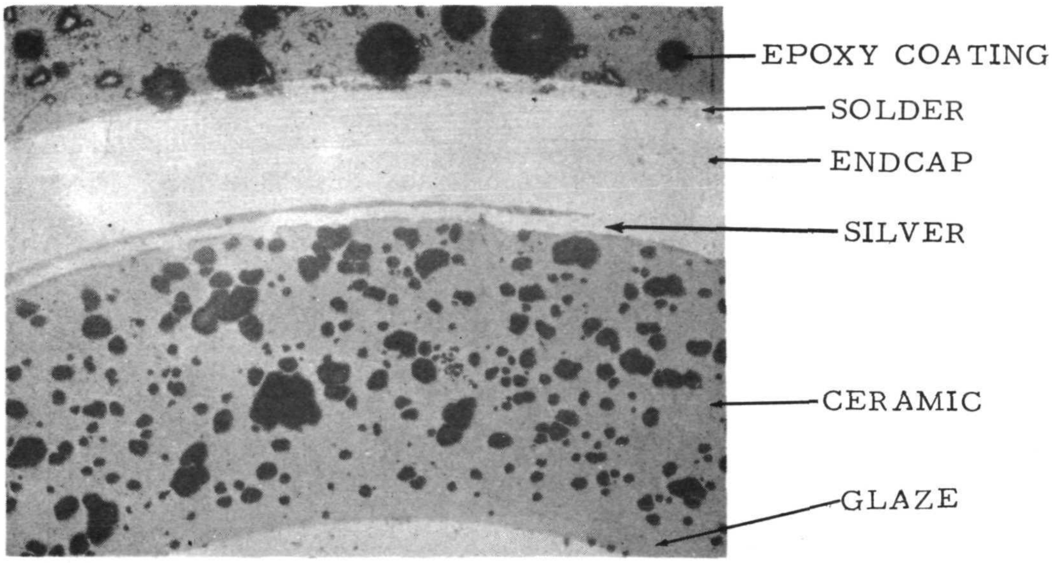


Photo 3: Transverse Cross Section of Good Resistor S/N 191

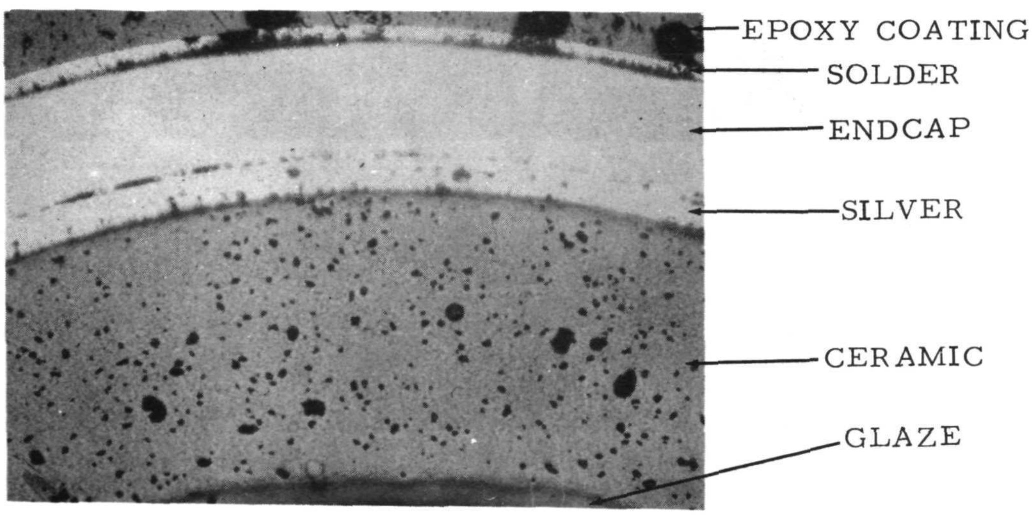


Photo 4: Transverse Cross Section of Bad Resistor S/N 58

Figure 7. Comparison of Porosity of Good and Bad Resistors, (100X)
(Sheet 2 of 2)

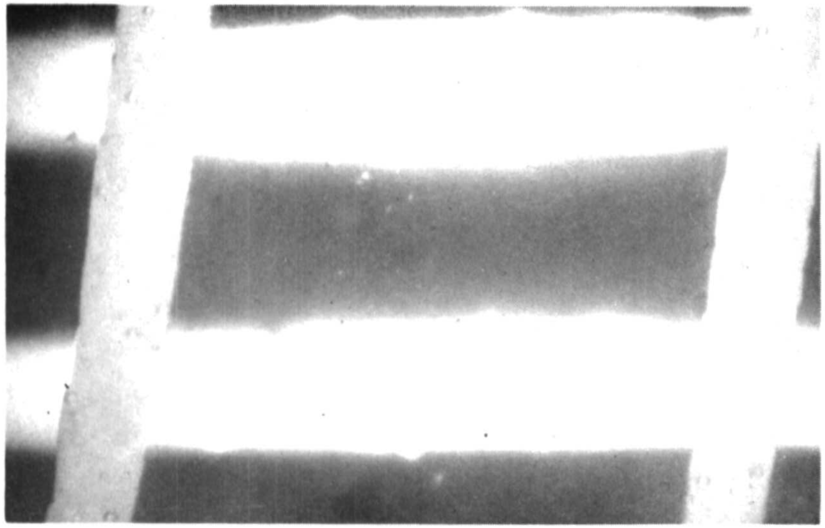


Photo 1: Stock Resistor S/N 38 (R)

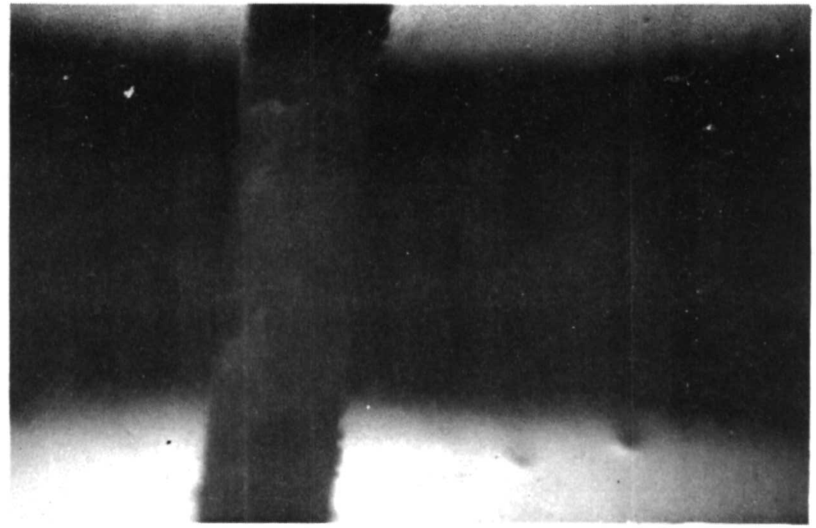


Photo 2: Bad Resistor S/N 123 (W)

NOTE: Edges of cut in film shows varying degrees of irregularities.

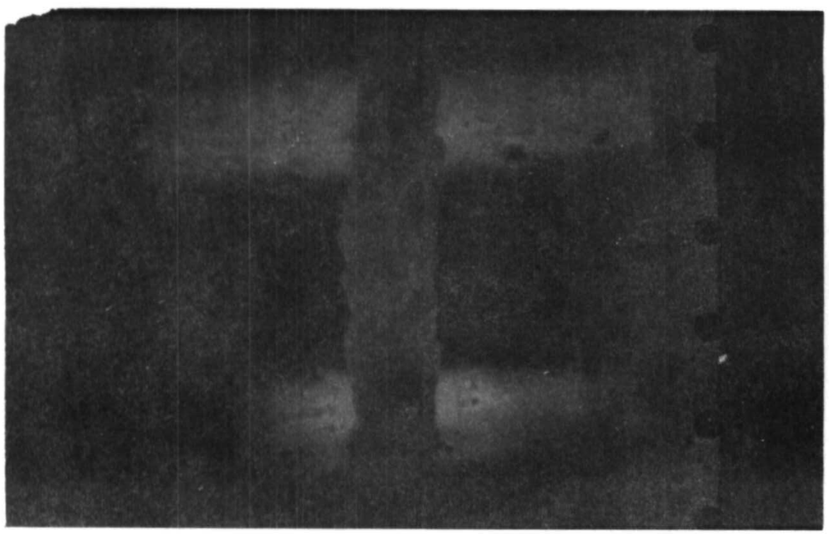


Photo 3: Bad Resistor S/N 68 (R)

Photo 4: Bad Resistor S/N 125 (W)

Figure 8. Photographs of Metal Film of Resistors.

film deterioration appears as a "scalloped" effect (photo 2). Erosion normally occurs only in localized areas of the film surface, i.e., not all film edges in a resistor are attacked. Isolated instances of spots of contamination or corrosion were found on the film surfaces (see figure 9), but do not appear to be associated with resistance changes.

The depth of the spiral cut in relation to the thickness of the glaze was evaluated on several resistors. The depth on all examined was less than half the glaze thickness. Figure 10 shows a cut of 0.1 to 0.3 mil on a glaze thickness of 1.5 mil.

Because of the extreme thinness of the metal film (less than 1000 angstroms) it is not possible to see the true cross section of the film using light microscopy. By sectioning through the film at an angle closely parallel to its surface, however, some indication of the nature of the film can be obtained. Figure 11 shows such a cross section of film of a bad resistor, S/N 206. The film thickness appears irregular, having protrusions (or bumps) which are thick deposits.

Two resistors were examined which had "infinite" resistance after burn-in. These were 301k ohm resistors, date coded 7031 and 7032. One resistor, S/N 35 (W), was opened by cutting off each endcap to permit viewing of the film prior to slitting longitudinally. It was observed that a considerable number of edges of the film at the spiral cut was eroded and, as shown in figure 12, one spiral was completely missing in some areas along the circumference. Similar conditions were found in resistor S/N 31 (W) (see figure 13). The cross section of one end of the resistor showed gross voids in the silver coat at the ceramic tube end; and the ceramic retained moisture more readily than other resistors after the post-polishing drying (with compressed air). The porosity of these two resistors, however, does not appear to be significantly greater than others examined.

(4) For additional information on microscopic analyses on Vamistor resistors refer to Section III, Paragraph A of Materials Division Vamistor Resistor Report (Appendix A).

d. Failure Analysis. A failure analysis was performed on five resistors. The first resistor was obtained from the nondestructive stress test and had drifted 38 percent since the start of test. Applied voltage was 5 percent of rated voltage and had been applied for 12 hours. The test temperature was 5 degrees C. Epoxy paint was removed and the resistor was circumferentially cracked, using laser for scribing. Visual inspection revealed film depletion from one end and the presence of brown, graying deposits at the opposite end. A dendrite-like residue was noted on the metallization. This resistor was sent to IBM, Owego, for microprobe analysis and trace amounts of potassium and chloride

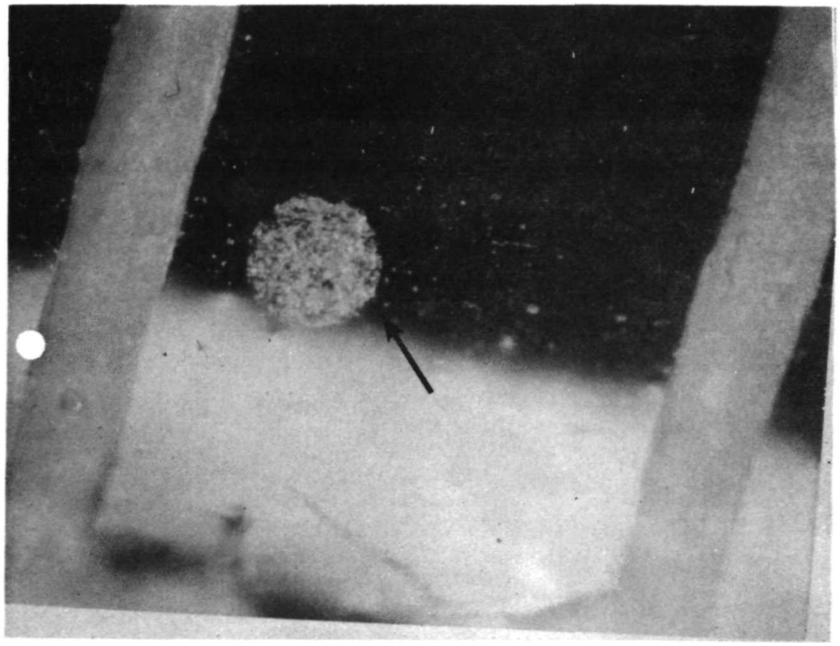


Photo 1: Good Resistor S/N 231

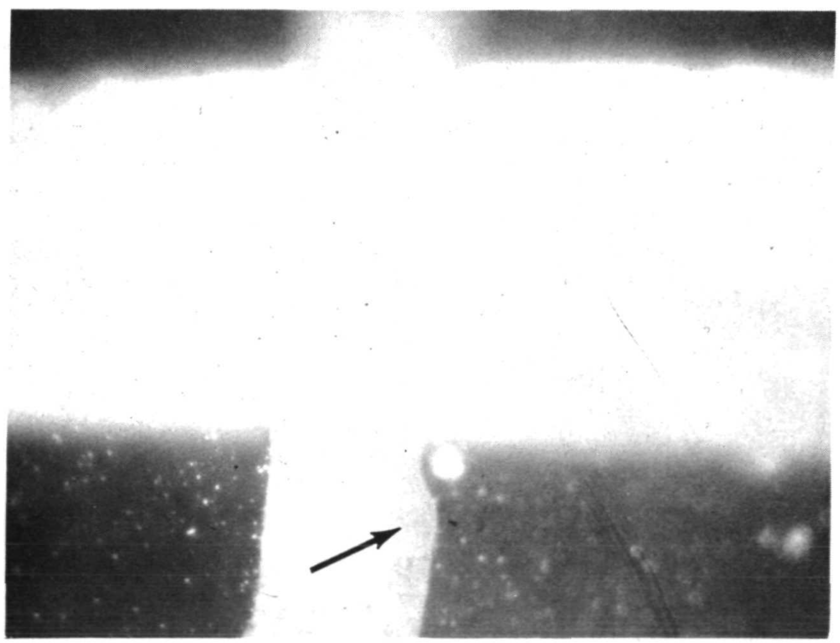


Photo 2: Bad Resistor S/N 139

NOTE: Arrows point to deviation at edge of film around spot (photo 2) and the smooth surface of glaze where film was originally.

Figure 9. Spots of Contamination/Corrosion in or on Metal Film.

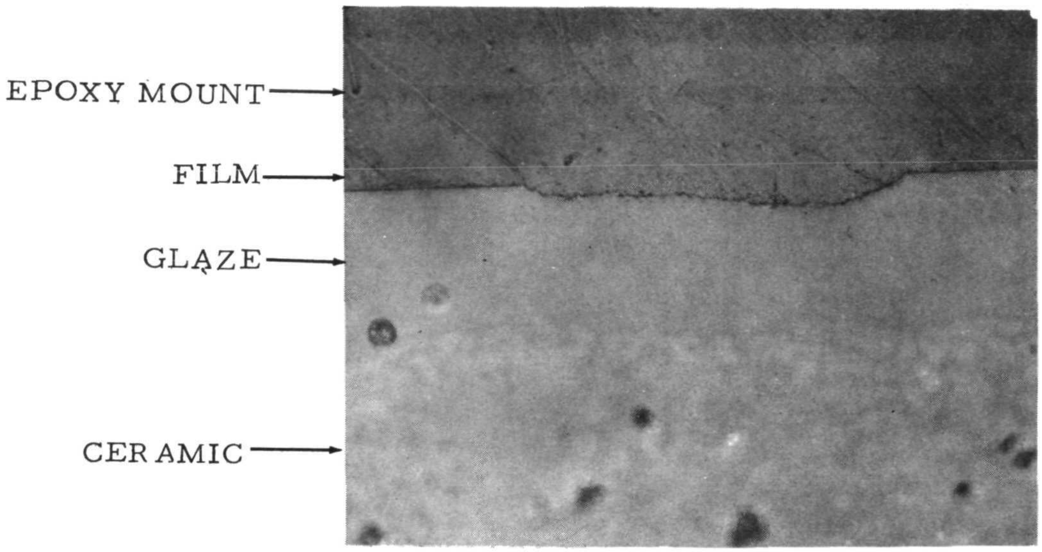


Photo 1: Depth of Cut is 0.1 to 0.3 mils

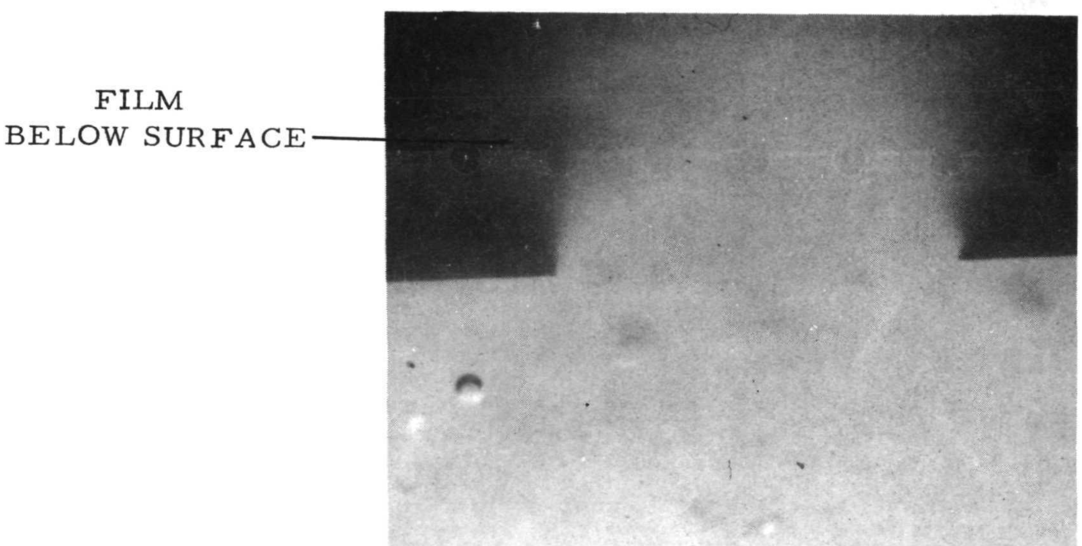


Photo 2: Same area as Photo 1 using polarized light to show film below surface of epoxy.

Figure 10. Cross Section of Bad Resistor S/N 219 Through Cut in Film (500X)

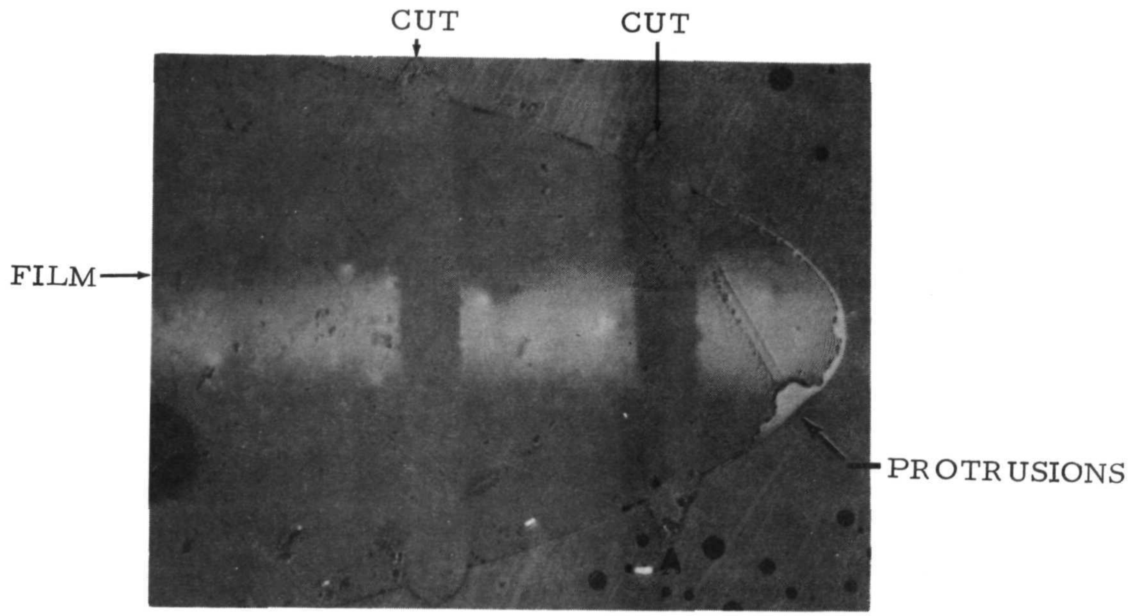


Photo 1: 125X Thick Protrusions in Film and Pores in Ceramic Glaze

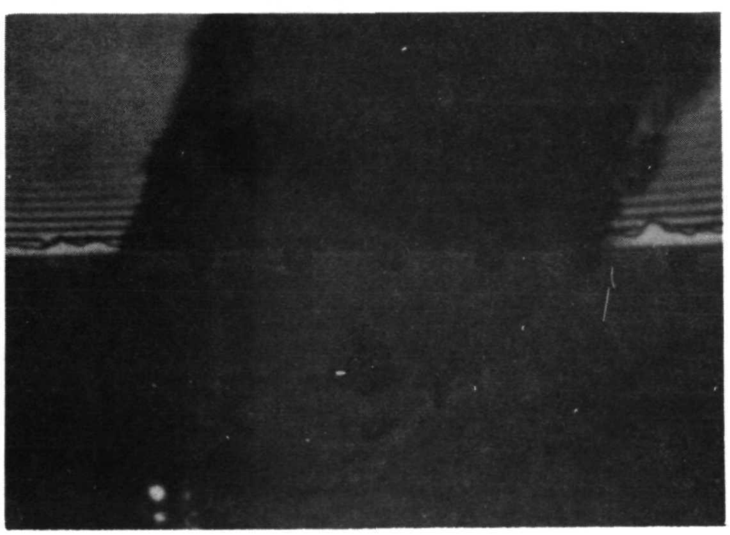


Photo 2: 1000X Cut in Film of Photo 1 at Position A (Arrow Points to irregular edge on shallower side of cut)

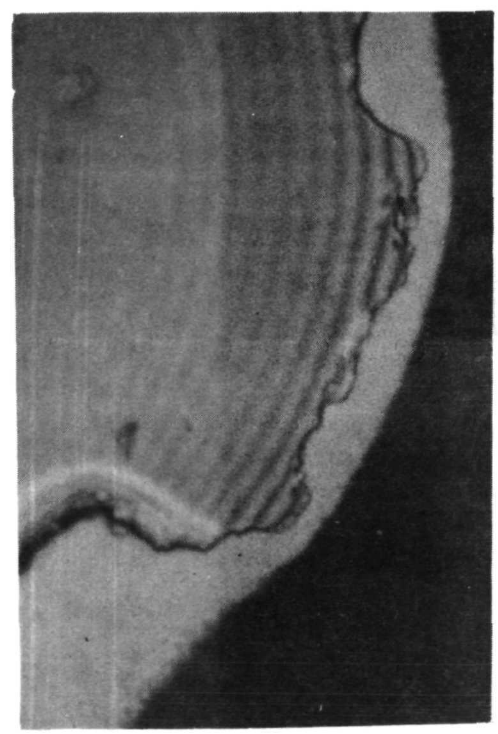


Photo 3: 1000X End of Film in Photo 1. (Shows uneven thickness of resistive film.)

NOTE: Resistor cross sectioned at shallow angle to film surface to show film characteristics. (Lines are due to light interference between reflections from polished surface and metal film.)

Figure 11. Photomicrographs of Bad Resistor S/N 206

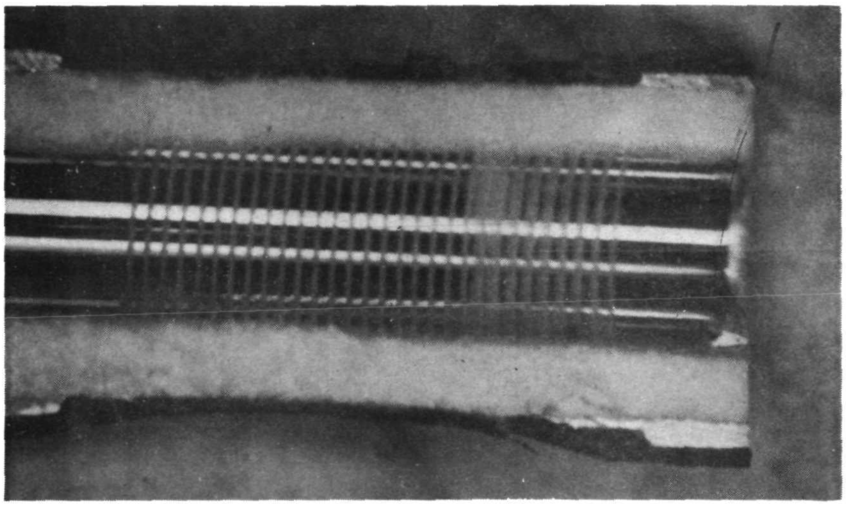


Photo 1: 10X

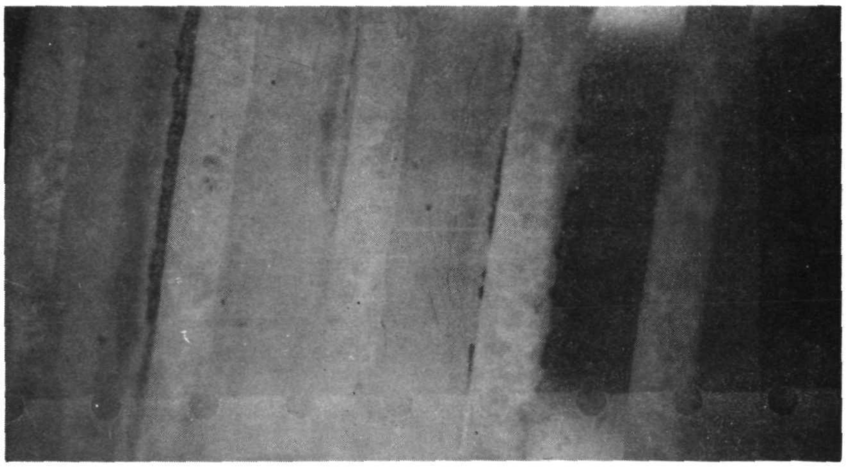


Photo 2: 70X

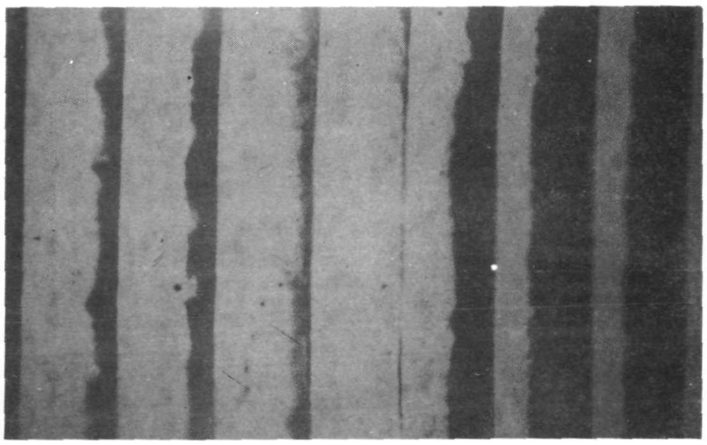


Photo 3: 50X Polarized Light (Through Epoxy Mount)

Figure 12. Gross Erosion of Bad Resistor S/N 35 (W)

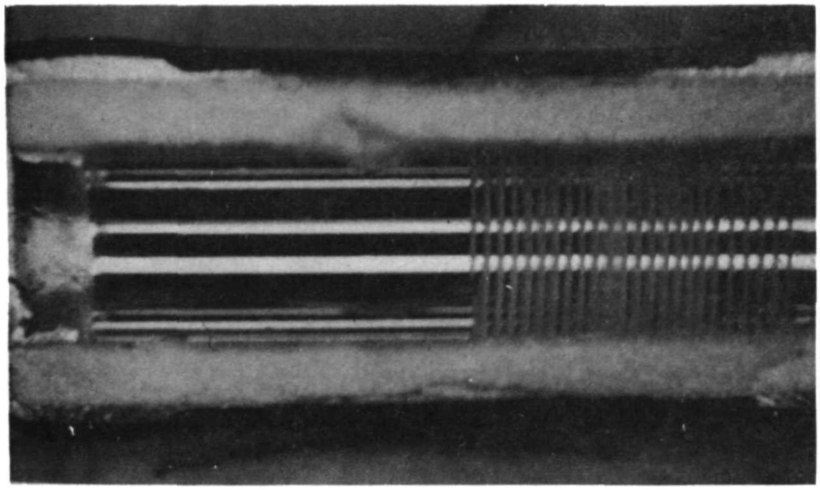
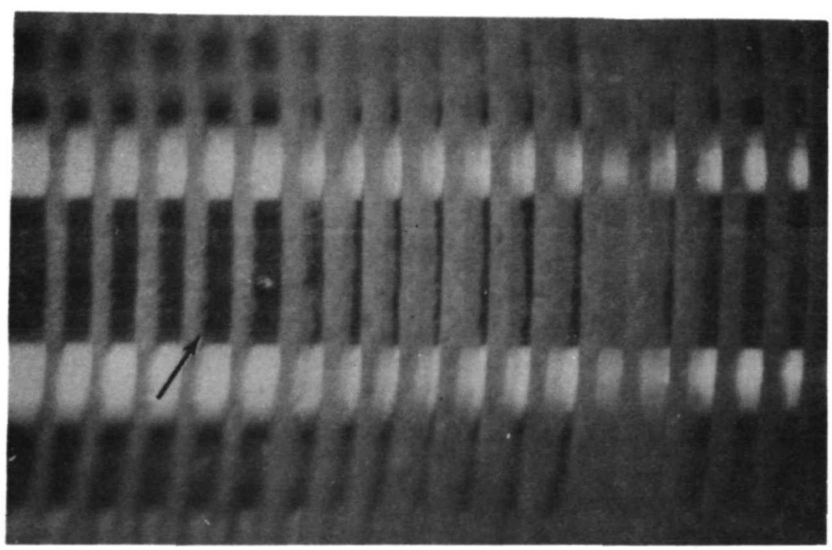


Photo 1: 10X



NOTE: Scalloped edges (arrow) on some spiral cuts similar to that shown in figure 8 photo 2.

Photo 2: 70X

NOTE: Occurred similar to that of resistor S/N 35 (W) figure 12

Figure 13. Photographs Showing Erosion of Bad Resistor S/N 31 (W) (Sheet 1 of 2)

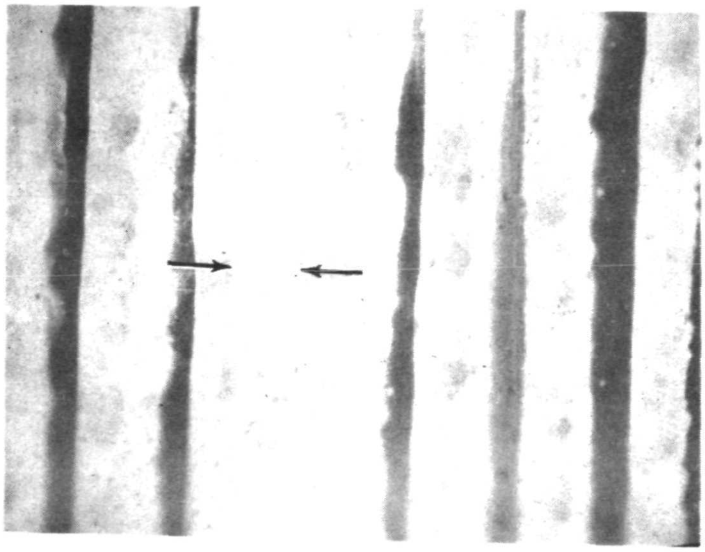
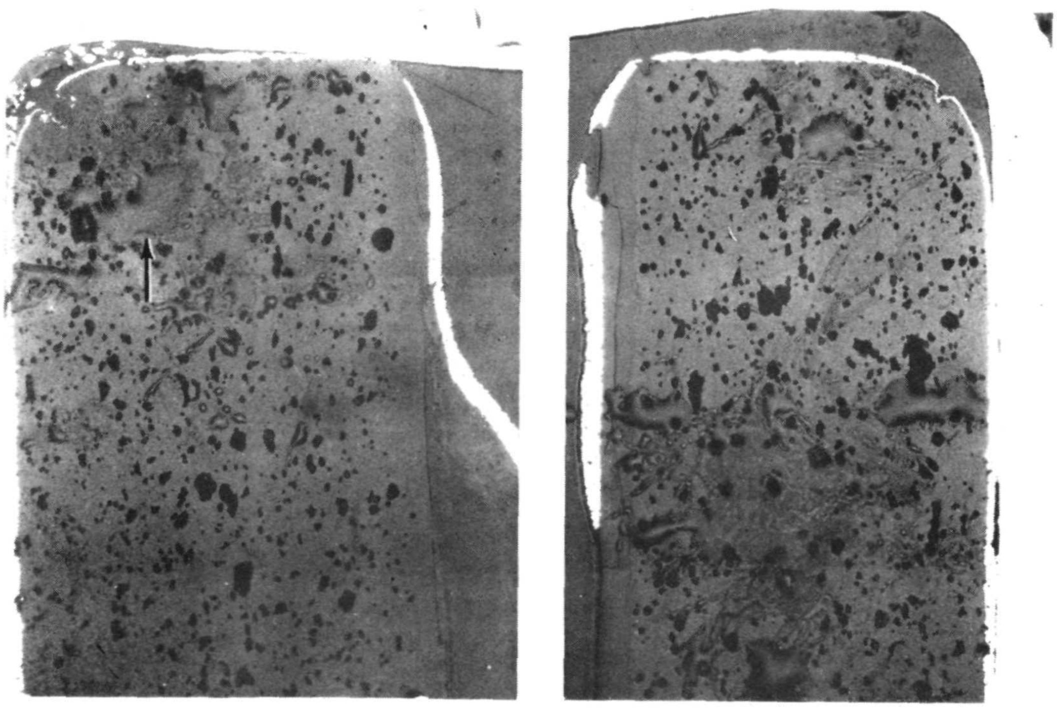


Photo 3: 70X (Polarized Light) Complete Erosion of Film (Area between Arrows)



NOTE: Smooth appearing areas on ceramic is retained moisture (typified by arrow). The ceramic at one end of resistor retained more moisture than normal after polishing and had gross voids in silver coating.

Photo 4: 50X Endcap and Silver over Ceramic Tube Ends

Figure 13. Photographs Showing Erosion of Bad Resistor S/N 31 (W) (Sheet 2 of 2)

were identified. Two of the remaining four resistors, S/N 27 and S/N 473, had been removed from WCIU 3 hardware and placed in nondestructive testing. S/N 473 had drifted one percent (0.9 percent above tolerance) in the hardware and S/N 27 had not drifted out of tolerance. After 99 hours of nondestructive testing, S/N 473 showed greater than 12 percent drift and S/N 27 showed greater than 13 percent drift. To determine if the drift was due to case seal leakage, the parts were baked for 48 hours in a N_2 atmosphere at 105 degrees C without power. The parts were then vacuum baked for 2 hours and vorite coated. Power was applied and the parts continued to drift. S/N 473 was measured open at the 191 hour point. S/N 027 had continued to drift at the same rate as before baking and coating. Epoxy paint was removed and a leak test was performed; neither part leaked. Endcaps were removed and the resistors were opened, by laser scribing and cracking, along the length of the resistors. Visual examination revealed the following:

(1) <u>Resistor S/N 27.</u>

(a) Solder ball
(b) Residues/Film on metallization
(c) Metallization removed from both sides of spiral indicating polarity reversal during testing.
(d) Has 7 spirals/turns

(2) <u>Resistor S/N 473.</u>

(a) Metallization of one spiral completely depleted producing open
(b) Numerous solder balls
(c) Residues/Film on metallization
(d) Has 3.5 to 4 spirals/turns

Photographs of these resistors are shown in Figures 14 through 16. SEM X-ray analysis of S/N 473 identified potassium, chloride, chromium, nickel, tin, and lead.

The remaining two resistors, S/N 64 and S/N 211, had both been removed from nondestructive stress testing after 13 hours at 20 to 30 percent VR and 25 degrees C. Resistor S/N 64 had not drifted, while S/N 211 had drifted approximately four percent from the value of the initial resistance measurement. Figures 17 and 18 shows the results of SEM X-ray analysis of both resistors.

3. <u>Nondestructive Seal Leak Analysis.</u>

a. <u>General.</u> The following seal leak test methods were em-

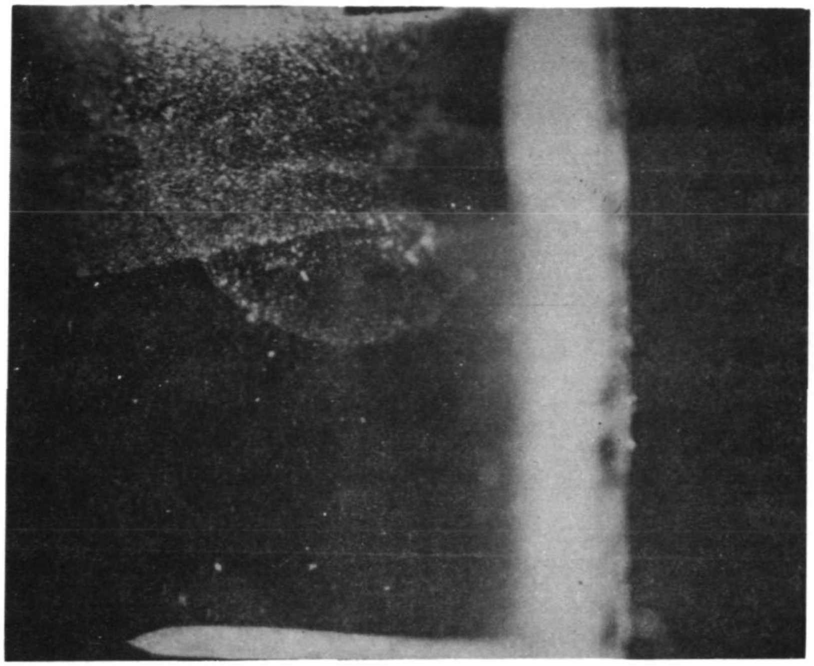


Photo 1: 40X Shows internal residue on metallization.

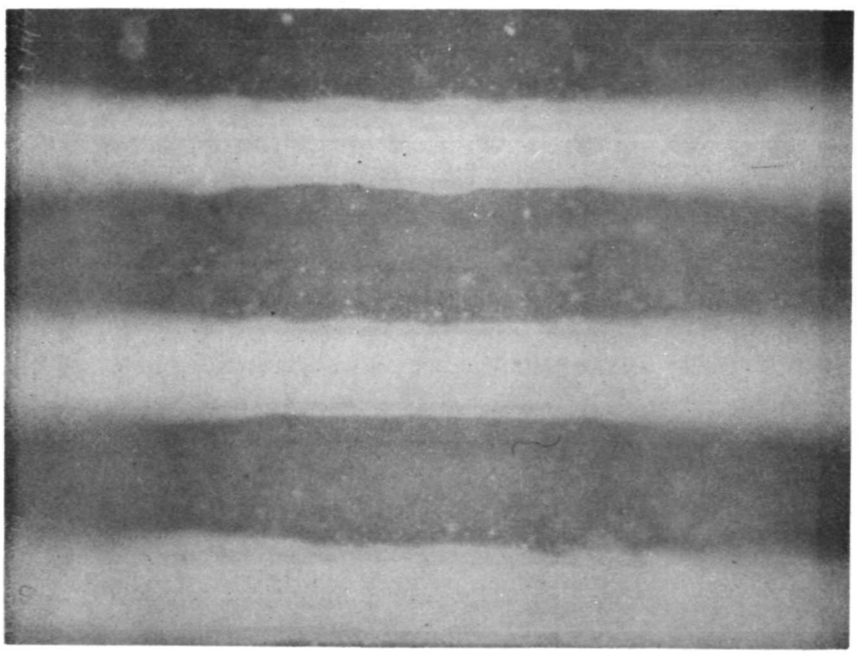


Photo 2: 80X Shows metallization removed from both sides of spiral.

Figure 14. Light Optic Photograph of S/N 27 Resistor

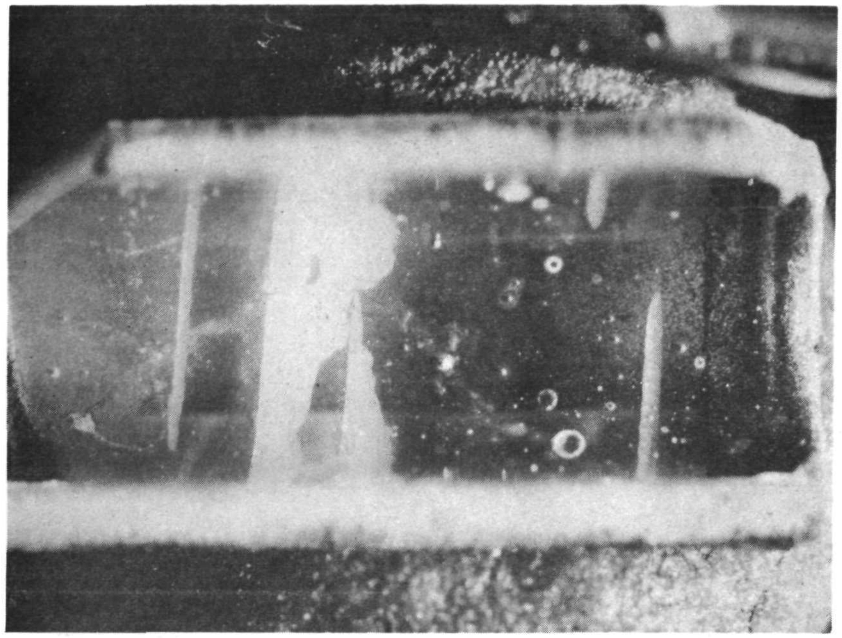


Photo 1: 27X

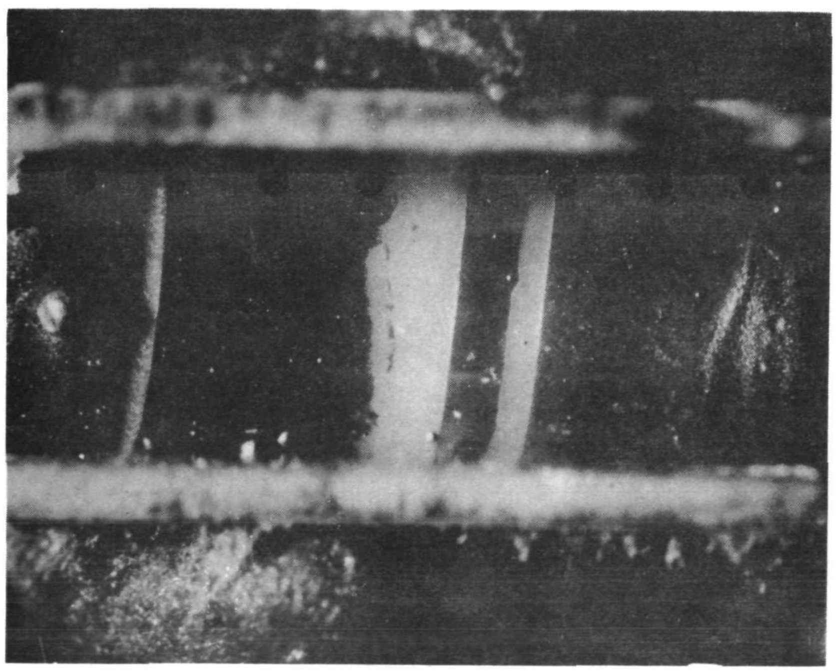


Photo 2: 27X

NOTE: Shows metallization depletion, numerous solder balls, and residual silver on metallization.

Figure 15. Light Optic Photographs of Resistor S/N 473

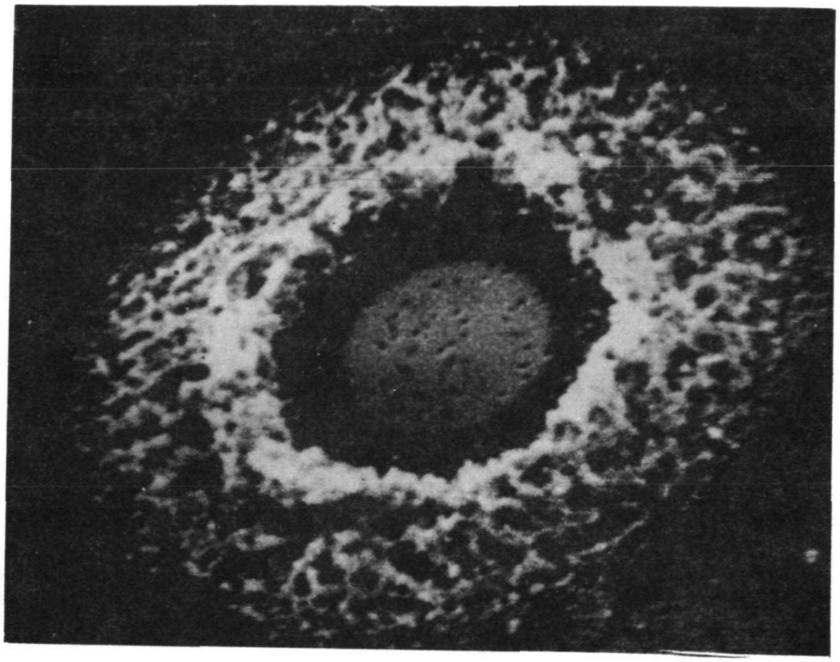


Photo 1: 500X

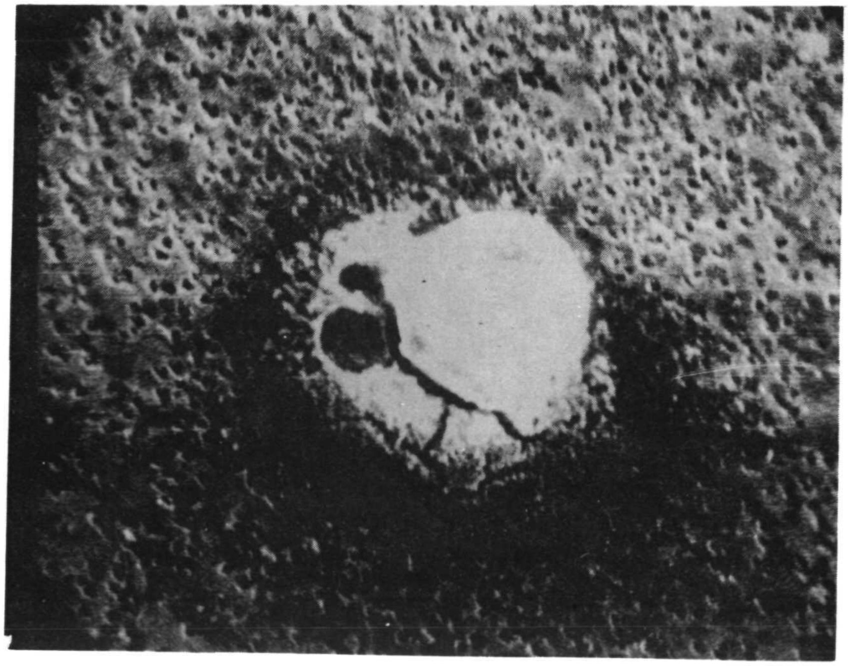


Photo 2: 500X

Figure 16. SEM Photographs of Solder Ball and Residue around Solder Ball of Resistor S/N 473

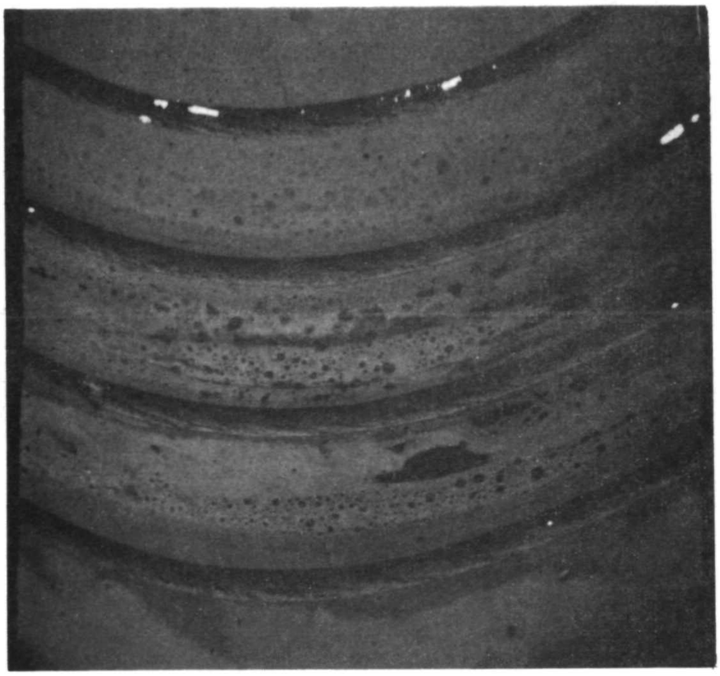


Photo 1: 75X Taken at 2KV (low voltage). Compare with figure 18 Photo 1.

NOTE: Materials cannot be identified on x-ray at this voltage. There appears to be a film over the resistive material.

Figure 17. Photographs of Failed Resistor S/N 211 (Sheet 1 of 5)

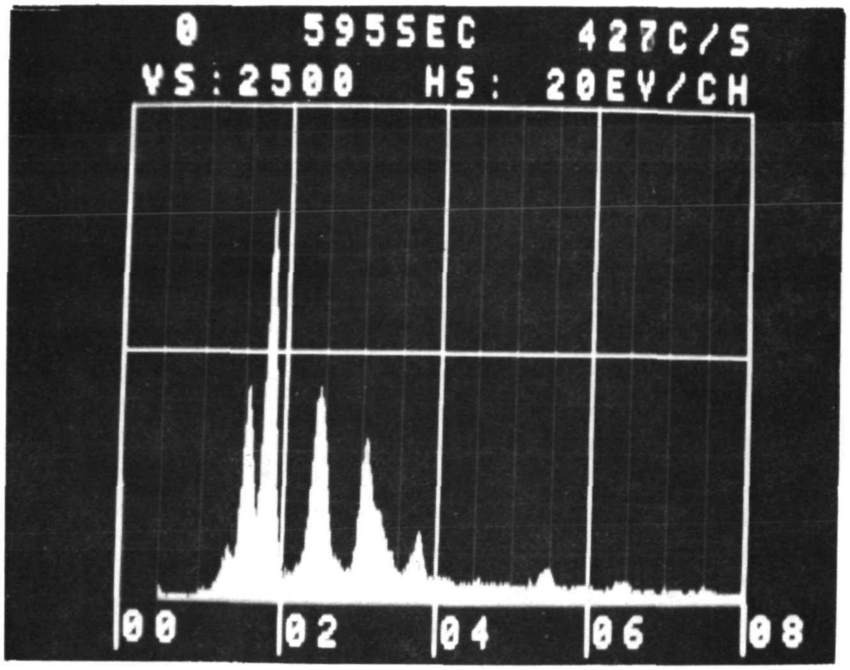


Photo 2: The materials of this sample of S/N 211 (Photo 1) are identified as follows:

1.	Magnesium (mg) or arsenic (As)	Ceramic
2.	Aluminum (AL)	Ceramic
3.	Tungsten (W) or Silicon (Si)	
4.	Sulphur (S), molybdenum (Mo), or lead (Pb)	Ceramic
5.	Silver (Ag)	Plastic
6.	Calcium (Ca)	Ceramic
7.	Chromium (Cr)	
8.	Iron (Fe)	
9.	Nickel (ni)	

NOTE: Compare with figure 18 photo 2

Figure 17. Photographs of Failed Resistor, S/N 211 (Sheet 2 of 5)

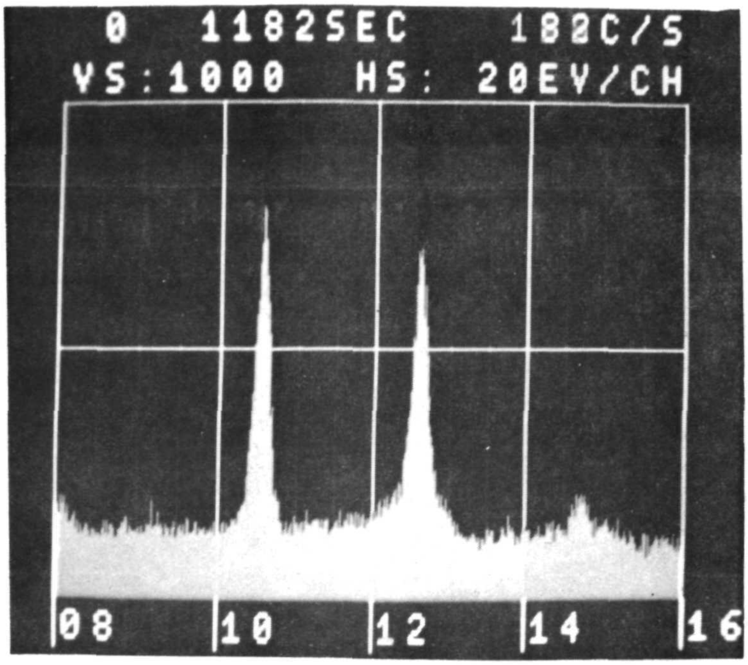


Photo 3: Lead (Pb) Compare with figure 18 photo :

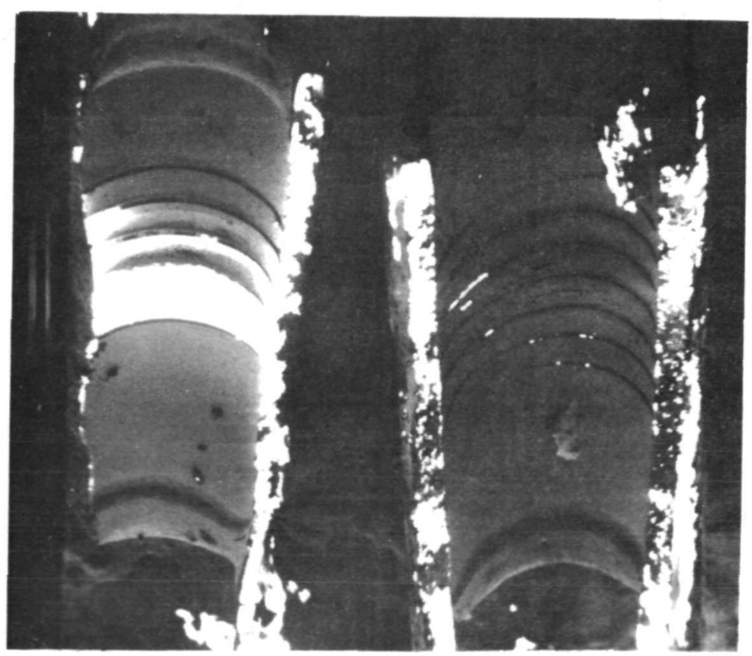


Photo 4: 30KV Note irregularities in resistive material. Compare with figure 18 photo 3.

Figure 17.| Photographs of Failed Resistor S/N 211 (Sheet 3 of 5)

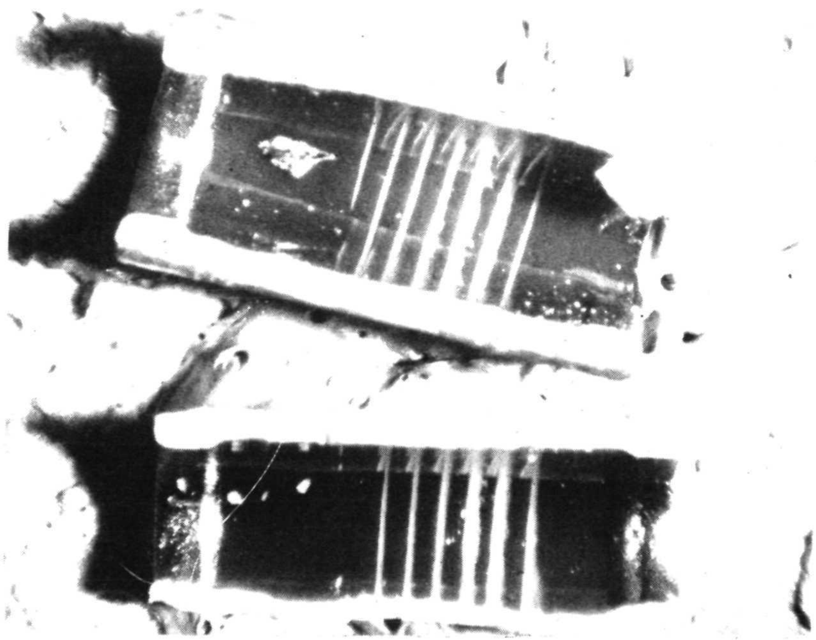


Photo 5: 25X the irregularities in the helix of this photo corresponds to those shown in Photo 4. Also the resistive material between spirals is missing.

Figure 17. Photographs of Failed Resistor S/N 211 (Sheet 4 of 5)

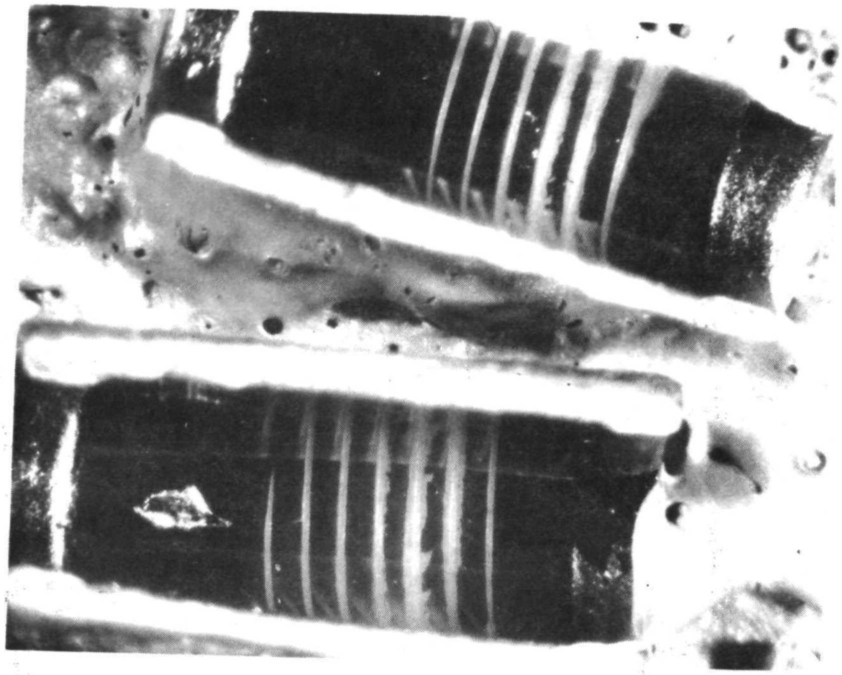


Photo 6: 16X Compare with figure 18 photo 4.

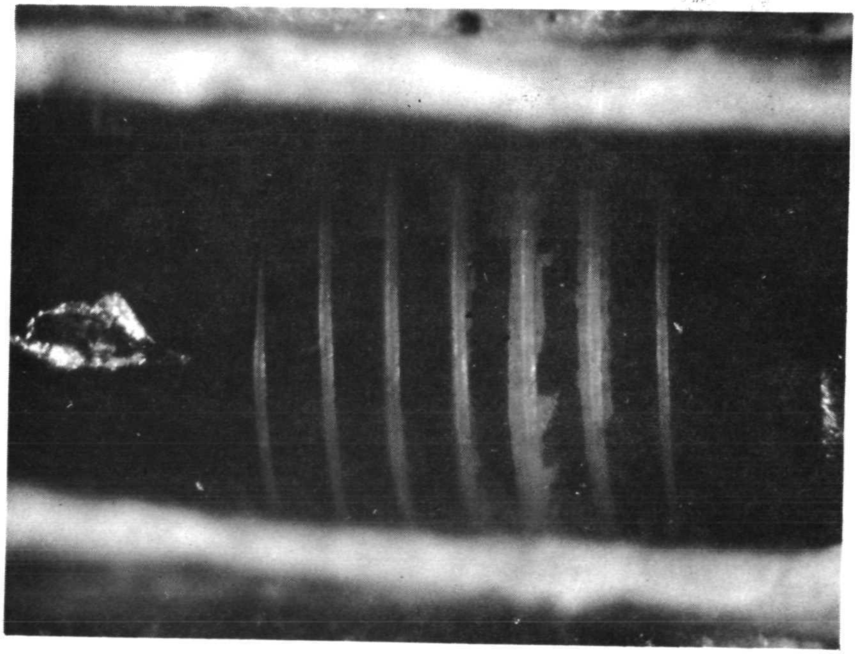


Photo 7: 30X Compare with figure 18 photo 5.

Figure 17. Photographs of Failed Resistor S/N 211 (Sheet 5 of 5)

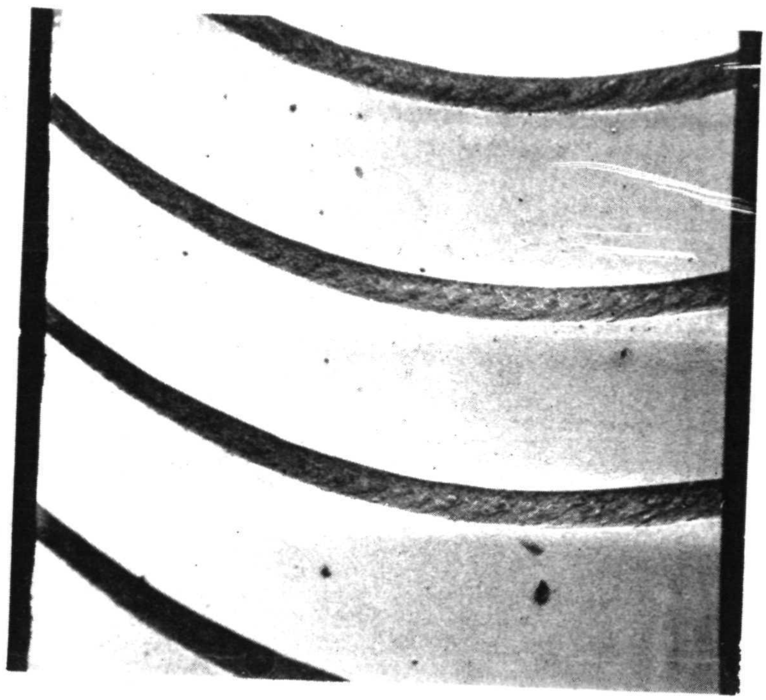


Photo 1: 75X Compare with figure 17 photo 1

Figure 18. Photographs of Good Resistor S/N 64 (Sheet 1 of 3)

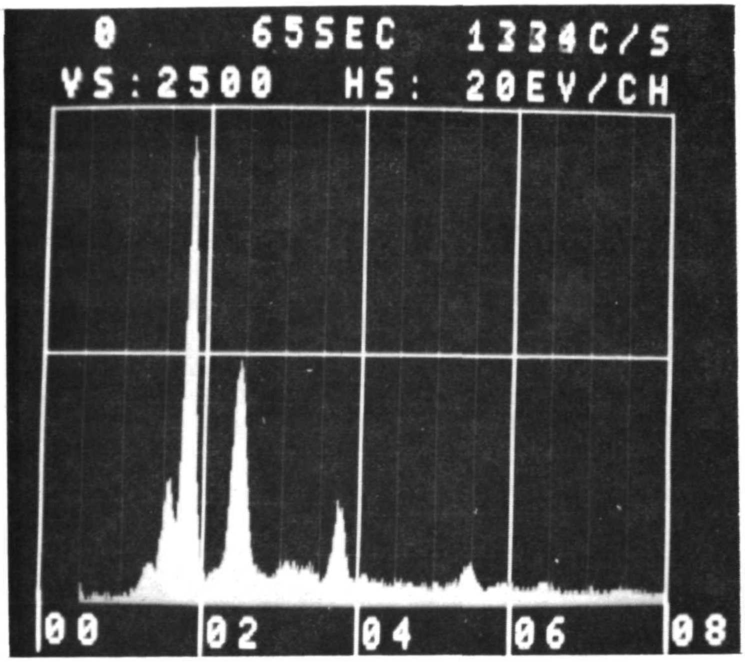


Photo 2: 20KV Compare with figure 17 photo 2.

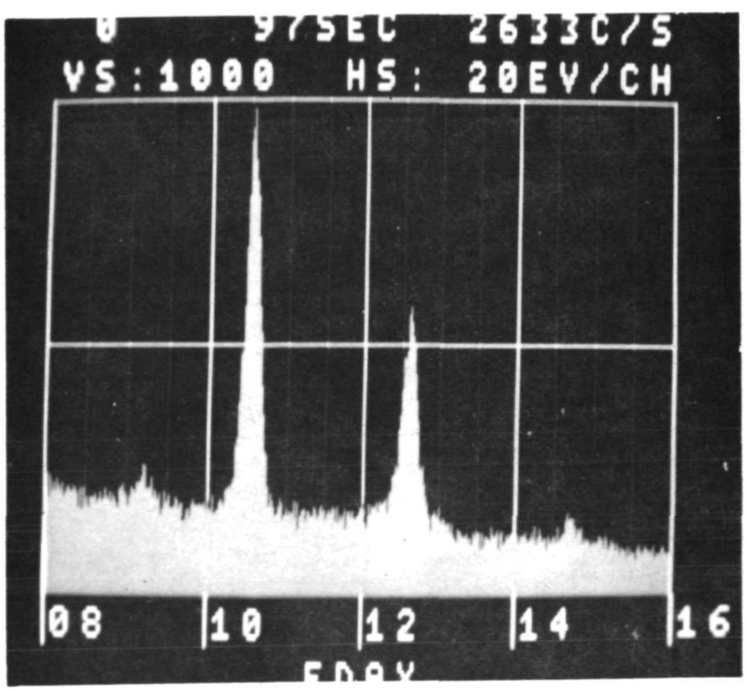


Photo 3: 30KV Compare with figure 17 photo 3.

Figure 18. Photographs of Good Resistor S/N 64 (Sheet 2 of 3)

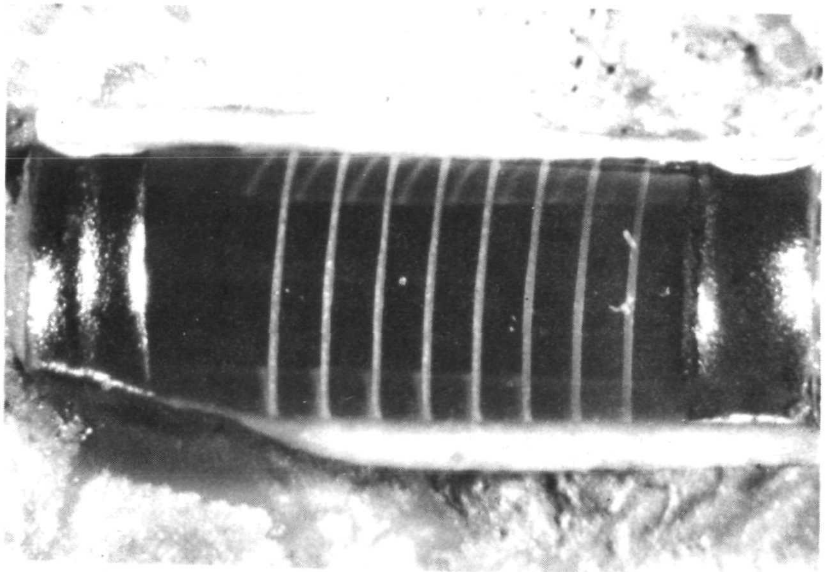


Photo 4: 12X Compare with figure 17 photo 6.

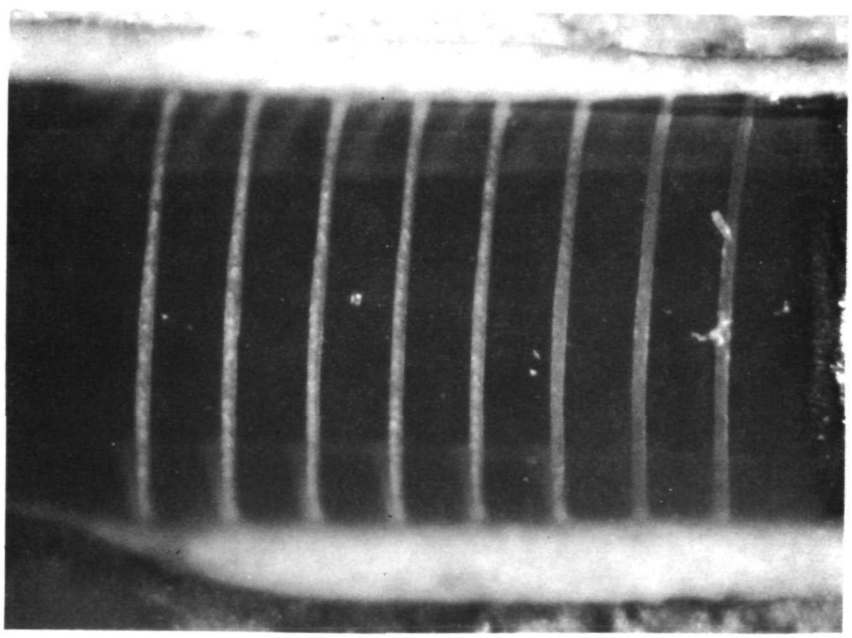


Photo 5: 30X Compare with figure 17 photo 7.

NOTE: The small spots are probably pieces of ceramic caused by the opening process.

Figure 18. Photographs of Good Resistor S/N 64 (Sheet 3 of 3)

ployed in performing the nondestructive seal leak analyses:

(1) Radioisotope Wet Gross and Fine Leak Tests. S&E-QUAL-AFT performed the radioisotope wet leak tests (hereinafter called the Radiflo test method) in accordance with procedures outlined in MIL-STD-750A, Method 1071, Test Condition A, to detect gross leaks and Test Condition G to detect fine leaks.

The resistors were first tested using the Radiflo test method to discover fine leaks. Any resistor exhibiting a leak rate equal to or greater than 1.0×10^{-8} cc/sec (of Krypton-85) was considered a fine leak failure.

Gross leak tests (to 10^{-6} cc/sec) were then performed on all resistors. Fluorochemical fluid absorbtion medium (FC-43) was substituted for reagent grade mineral oil in this procedure. Any resistor, from a visual hole to one indicating 200 counts per minute (or greater) above the ambient background of the counting station, was considered a gross leak failure.

(2) Tracer Gas Helium (He) Fine Leak and Fluorocarbon Gross Leak Tests. IBM performed He fine and fluorocarbon gross leak tests in accordance with procedures outlined in MIL-STD-883, Method 1014, Test Condition A and Test Condition C, respectively, to detect fine and gross leaks in Vamistor resistors.

The resistors were first tested using the He bombardment method of testing for fine leaks. If the resistor exhibited a measured leak rate corresponding to 5×10^{-8} cc/sec He or greater it was considered a fine leak failure. Fluorocarbon gross leak tests were then performed on all resistors. A gross leaker is identified by a bubble or stream of bubbles. For testing Vamistor resistors, a resistor was not classified a gross leaker unless a stream of bubbles continued for 1 minute. This criteria was specified to differentiate from trapped air in pin holes and voids.

b. MSFC/IBM Seal Leak Correlation Testing. Seal leak analyses were performed on 104 Vamistor resistors by S&E-QUAL-AFT and by IBM (using alternate test methods) to determine if the resistors were leakers and, by correlation of test results, ensure an adequate test program to verify the integrity of the hermetic seals. The following test program was conducted to correlate test results obtained at MSFC and IBM (see table 12).

Table 12. Summary of MSFC/IBM Seal Leak Correlation Testing

Resistors	Test I Lot of 49 Epoxy removed not serialized	Test II Lot of 25 Epoxy not removed not serialized	Test III Lot of 30 Epoxy removed serialized
1st Tested By	S&E-QUAL-AFT	S&E-QUAL-AFT	IBM
1st Test Results	1 gross leaker No fine leakers	No gross leakers No fine leakers	7 gross leakers 6 fine leakers
2nd Test By	IBM	IBM	S&E-QUAL-AFT
2nd Test Results	1 gross leaker 16 fine leakers	19 gross leakers 25 fine leakers	5 gross leakers No fine leakers
Additional Testing, Investigation, and Remarks	16 fine leakers retested by IBM using bake out after bombardment with helium. One fine leaker resulted. Part was cleaned and retested. Part did not leak.	Epoxy was removed from the devices and retested by IBM utilizing the bake out technique. No gross leakers and 2 fine leakers were detected. The 2 fine leakers were tested by S&E-QUAL-AFT using the radiflo and verified as leakers.	S&E-QUAL-AFT could not verify S/N 544 & 535 as leakers using radiflo. AFT performed bubble tests on these units. S/N 535 showed no bubbles. S/N 544 showed bubbles but seemed to be coming from a spot of material on the body of the resistor. Both devices were retested by IBM. S/N 535 did not leak. S/N 544 was cleaned and retested at IBM. More bubbles were found than before. S/N 544 Radiflo tested after cleaning and was a leaker. The IBM fine leakers were baked out and retested and did not leak.
Total IBM	1 gross leaker	2 fine leakers	6 gross leakers
Total AFT	1 gross leaker	2 fine leakers	6 gross leakers

(1) Test I. A total of 49 Vamistor resistors (not serialized) from which the epoxy had been removed were leak tested by S&E-QUAL-AFT using the Radiflo test method. The only leaker detected was a gross leaker. These 49 resistors were then tested by IBM using their techniques. The one gross leaker detected by S&E-QUAL-AFT was confirmed by IBM; however, using the He leak detection method, IBM found 16 fine leakers that were not detected by S&E-QUAL-AFT. Additional investigation by IBM revealed that the body of the resistor was being impregnated with the He, thereby giving a false indication that a resistor was a leaker. After conferring with engineers at IBM, it was determined that when the resistors were baked at 100 degrees C for 15 minutes and retested, only one of the original 16 designated by IBM as leakers had leaked. The leak in this resistor was 1.8×10^{-8} cc/sec, which is within the specified limits.

(2) Test II. A total of 25 resistors with the epoxy still on them were leak tested by S&E-QUAL-AFT. No leakers were found. These same resistors, when leak tested by IBM, indicated 19 gross leakers and all 25 were fine leakers.

The epoxy was then removed and leak tested again. There were no gross leakers; however, two of the 25 were still fine leakers. The two fine leakers were baked out, retested by IBM and they were still leakers. The two fine leakers were retested by S&E-QUAL-AFT using the Radiflo test method and it was verified that they were leakers.

(3) Test III. S&E-QUAL-AFT received 30 Vamistor resistors (serialized) with epoxy removed that had been leak tested by IBM. These resistors were leak tested by S&E-QUAL-AFT using the Radiflo test method, and the following were gross leakers: S/N 297, 363, 546, 454, and 38. Four of these resistors were determined to be gross leakers utilizing the radioisotope wet gross leak test depicted in MIL-STD-750A, Method 1071, Test Condition A. No fine leakers were detected. After the testing by S&E-QUAL-AFT was completed, IBM was contacted to learn the results of their testing on these same resistors. Resistors S/N 38, 297, 363, 454, 535, 544, and 546 were given by IBM as being gross leakers with an additional fine leaker. The test results by IBM and S&E-QUAL-AFT coincides, except for S/N 535, 544, and the six fine leakers. Additional testing was performed on these two resistors by S&E-QUAL-AFT. They were subjected to a bubble test utilizing FC-43 as a test media. This is the same type test used by IBM for gross leak tests. Bubbles were detected on S/N 544 and no bubbles were detected on S/N 535. S/N 544 was given a visual examination under a microscope and a small spot of epoxy material was found on the resistor. An additional bubble test was performed with a microscope, concentrating on this spot of material and it was discovered that the bubbles were coming from this epoxy material. These two resistors, S/N 544 and 535, were returned to IBM for reconfirmation of their bubble test. Retest at

IBM on 1-4-73 showed bubbles on S/N 544 and none on 535. S/N 544 was cleaned and still showed even more prominent bubbles. IBM retained S/N 535 for continued investigation. S&E-QUAL-AFT retested S/N 544 on Radiflo and found it to be a leaker. The IBM fine leakers were baked out, retested, and did not leak.

c. Other Seal Leak Tests. Seal leak tests were performed on 22 Vamistor resistors removed from WCIU S/N 1, 3, and ATMDC 4. Six of these resistors had drifted beyond tolerance and five others were selected as potential drifters, based on resistance measurement being on the plus side of nominal. This resulted in two samples of 11 resistors each for chemical analysis of a good group and a potentially bad group. Gross leak test in FC 43 at 125 degrees C was performed prior to epoxy paint removal and all were leakers. After paint removal, 16 were still leakers. The six non-gross leakers were fine-leak tested per MIL-STD-883, Method 1014 and one was a leaker. Gross leak test results on these resistors are believed to be questionable due to further refinement of the test techniques required to allow for anomalies attributable to part design (see paragraph 3.b above). Since these resistors were further subjected to destructive analysis they cannot be retested using the new technique.

To further explore the quality of hermetic sealing of Vamistor resistors, gross and fine leak, and dye penetrant tests were performed on 40 additional resistors. Twenty of these parts were from hardware (10 each from WCIU S/N 1 and 3) and 20 from MSFC stock. The epoxy paint was removed using Dynasolve 160 and a visual inspection was performed. Pin holes and voids in the endcap fillet were noted on 75 percent of resistors. A resistor was not classified as a gross leaker unless a stream of bubbles continued for 1 minute. This criteria was specified to differentiate between leaks and entrapped air in pin holes and voids. The fine leak test also had to be refined by adding a 15 minute bake at 100 degrees C after bombardment with He to expel absorbed He in the ceramic tube. Samples were selected from each family of resistors for dye penetrant testing and may not have failed gross and fine leak test. The penetrant test was performed by placing the 10 samples and Zyglo penetrant in a cylinder, and bombing at 5 atmospheres for 2 hours. Results of leak tests are tabulated in table 13. The 30 resistors which saw only seal leak testing were given to MSFC for Radiflo testing to correlate IBM/MSFC results. The results of this correlation is presented in paragraph 3.b.(3), Test III in this section.

Table 13. Leak Test Results

Sample Origin	Quantity Tested	Failures Gross	Failures Fine	Zyglo
WCIU - 3	10	5	5	3 of 3
WCIU - 1	10	2	1	0 of 3
MSFC Stock	20	5	5	2 of 4

B. NONDESTRUCTIVE STRESS TESTING

1. General

a. Information on Vamistor Resistor Testing (Test Matrix). The varied applications of Vamistor resistors in space hardware necessitated a complex matrix of test conditions with respect to temperature and applied voltage. Test conditions were matrixed for a temperature range from minus 20 to plus 125 degrees C and an applied voltage range from 0.0 to 110 percent VR of the resistor. The conditions are presented in the matrix shown in table 14. A total of 3921 Vamistor resistors are currently under test. The matrix shows the number of resistors under test and number taken off of test (stopped) in any test cell. Most resistors tested were taken from MSFC stock; however, some were taken from space hardware and contractor stocks and will be identified later as special tests within the matrix.

Special test cases, which fall outside the matrix range, are included under matrix test cell number 71. They are operating at 25 degrees C and a VR of 125, 150, 175, and 200 percent. Also, in matrix test cell number 77, a test is being conducted at minus 40 degrees C and an applied voltage of 20 to 30 percent VR. The special case matrix test cell numbers were chosen because of computer program limitations.

b. Resistor Identification and Measurement. Before testing, resistors are carefully identified for traceability. The polarity, serial number, date code, group numbers, and matrix test cell number are recorded. Prior to each measurement, resistors are allowed to stabilize at 25 degrees C, regardless of test environment. The resistors are measured with an 8400A Fluke digital ohmmeter, or equipment having equivalent accuracy. Resistance measurements (R1) are made initially and subsequent measurements (x) are made at specified time intervals until 2000 hours of total test time has been accumulated. The resistance is measured and recorded to four significant digits.

c. Data Format. The computer program tracks each individual resistor according to serial number, date code, resistor range, test group, and matrix cell. The initial measurement is printed and subsequent measurements are recorded with respect to accumulated time in test. The delta resistance and percent increase from the original measurement is then computed. The computer printout provides summary data for each test group as follows:

(1) Number of parts in test group.
(2) Date Code of parts in test group.
(3) Resistor ranges.
(4) Test conditions.
(5) The percent defective at greater than 0.2, 1.0, 5.0, 10.0, 15.0, and 20.0 percent drift.

Table 14. Test Matrix

Environmental Temperature (Degrees C)

Percentage of VR DC Applied	-20	5	25	50	75	100	125
0.0	1 (21-S)	2	3 (19-S)	4 (20-S)	5	6 (20-S)	7 (20-S)
0.1	8 (50)	9 (70)	10 (69)	11 (50)	12 (90)	13	14 (49)
1.0	15 (49)	16 (70)	17 (111)	18 (50)	19 (50)	20	21 (50)
5	22 (50)	23 (69)	24 (77)	25 (49)	26 (50)	27	28 (80)
10	29 (80)	30 (70)	31 (85)	32 (50)	33 (50)	34	35 (49)
15	36 (50)	37 (80)	38 (69)	39 (50)	40 (80)	41	42 (50)
20 to 30	43 (80)	44 (70)	45 (903) (914-S)*	46 (70)	47 (70)	48 (69)	49 (90)
50 to 70	50	51 (50)	52 (65)	53 (50)	54 (50)	55	56
80 to 110	57	58 (50)	59 (60)	60 (48)	61 (50)	62	63
20/30 (dc pulse)	64	65	66 (50)	67	68	69	70
Special	71 25°C 50 @ 125% VR DC 50 @ 150% VR DC 50 @ 175% VR DC 50 @ 200% VR DC	72	73 (100-S) (50) at 20/30% VR AC	74	75	76	77 (50) at -40°C and 20/30% VR DC

LEGEND: Number enclosed in block is the cell number
Number enclosed in parenthesis is quantity tested
Letter S indicates testing discontinued

NOTE: *Includes 20 Ward Leonard resistors and 55 MEPCO resistors

(6) The maximum drift of any single resistor in that test group.

(7) The average drift of all the parts in that test group.

The data are further summarized by row (VR) and by column (Temperature) for the test matrix with data omitted for the special test cases. Special summaries are provided as follows:

(1) Percentage drift and percent defective versus date codes at all temperatures.

(2) Percentage drift and percent defective versus resistor ranges at all temperatures.

(3) Percentage drift and percent defective versus rated voltage at all temperatures.

(4) Percentage drift and percent defective versus temperature at all rated voltages.

(5) Percentage drift and percent defective versus time at all temperatures.

(6) Percentage drift and percent defective versus time at all rated voltages.

(7) Drift rate for population versus time at all percent drift defect criteria.

Data from the computerized summaries are plotted for a comprehensive view of the various trends developing in the test program. These graphs are presented, with discussion, later in this section.

2. <u>Data Analysis of Nondestructive Stress Test.</u>

a. <u>Data Analysis of Special Test Within Matrix.</u>

(1) <u>Drifters and Leakers Correlation Testing.</u> In an effort to determine whether or not a correlation existed between drifters and leakers and to determine the effect of vacuum on drifters, 16 known drifters were placed in a vacuum chamber at 10^{-4} torr with 20 to 30 percent VR applied. The vacuum pressure was attained prior to application of voltage. The first measurements were taken after 19 hours and then the 16 resistors were seal leak tested. No leakers were found. This indicated that drifters are not necessarily leakers. The resistors were then replaced in the vacuum chamber for a continuation of the vacuum testing. When the resistors were read at the 19 hour point there was a noticeable decrease in the drift rate of all 16 resistors. Eight resistors showed a decrease in resistance. The resistors were put back in the vacuum chamber and read at the 72, 144, and 295 hour point.

At this time 5 resistors showed greater than a 0.2 percent drift. The maximum drifter was 1.07 percent from the initial reading (R1), read prior to insertion in the vacuum chamber. The mean drift of the 16 resistors at this time, R5 at 295 hours, was 0.185 percent from R1. The resistors were removed from vacuum testing and returned to 20 to 30 percent VR at plus 25 degrees C and ambient pressure. Presently, the resistors have seen 1537 hours in this test with a mean drift of 0.44 percent from R5. This test is continuing.

Since the mean drift of the 16 resistors prior to vacuum testing was 3.63 percent in 287 hours, it can be seen that there was an appreciable decrease in the drift rate in approximately the same time period under vacuum testing (3.63 to 0.185). It can also be seen that the drift rate decreases in approximately the same time period after removal from the vacuum chamber and operated at ambient conditions. It is possible that the results of this test were biased by the fact that the 16 resistors had seen 287 hours of nondestructive stress testing, nine at 20 to 30 percent VR (-20 degrees C), and seven at 20 to 30 percent VR (+5 degrees C), prior to vacuum testing. The normal decrease in drift rate, with time, could be affecting the results. To remove this bias, stock resistors should be initially operated at a vacuum and then at ambient pressure for the same VR and temperature.

To further pursue the correlation of drifters and leakers, gross seal leak tests were performed on 240 resistors which had been removed from PC boards. These were 40M38732 pulser boards in the C&D Logic Distributor. Seven were found to be gross leakers. This could be attributed to stresses of removal. These seven units were placed on nondestructive stress testing at +25 degrees C and 20 to 30 percent VR. When the resistors were read at approximately 12 hours, S/N 30, a 95.3K resistor (date code destroyed during removal from PC boards), read 177.64K and the other six showed no drift. After 288 hours, S/N 30 showed infinite resistance and was removed for a failure analysis which has not been initiated as of this date. The other six resistors have completed 1683 hours of testing with no increase in resistance.

The result of the two above tests on drifters/leakers leads to the conclusion that all drifters are not necessarily leakers and vice versa. The results of the vacuum test was such that no concrete conclusion could be reached, because of the possibility that the test results were biased. For results of a vacuum test in which a hole is drilled in the resistor, removing the humidity, and exposing the inside of resistor to a vacuum refer to Section V, Paragraph B.1 of Materials Division Vamistor Resistor Report (Appendix A of this report).

(2) <u>Nondestructive Stress Testing of New Vamistor Resistors</u>. Nondestructive stress testing at 20 to 30 percent VR and +25 degrees C was conducted on Vamistor resistors which had been produced by Vamistor Division using a new process. This testing was performed to determine if the re-

sistors were still susceptible to the same failure mechanism. The tests were conducted as follows:

(a) Unscreened Vamistor Resistors. One hundred resistors which had been manufactured while MSFC monitored the production, including the new boiling wash technique, were tested. These resistors were pulled after the MIL Spec screening, but prior to the Vamistor installed screening of 8 hours burn-in at 20 to 30 percent VR and ambient temperature with a 0.05 percent drift reject criteria. The resistors were all RNR55C5002F, Date Code 7301. After 1783 hours of testing, 14 resistors have exceeded 0.2 percent drift with a maximum drifter of 17.5 percent. This result provides an indication that the new, boiling wash technique, alone, is not sufficient to eliminate the drift problem. This test is continuing.

(b) Resistors Passing Vamistor Screening Test. One hundred resistors (Date Code 7251) which had been through the MIL Spec screening and had passed the aforementioned Vamistor screening, were tested. After 1783 hours of testing, 8 resistors have exceeded 0.2 percent drift with one resistor falling open at 1130 hours, (S/N 20,200K). This result provides an indication that the Vamistor screening procedure is ineffective in detecting some drifters. This test is continuing.

(c) Resistors Failing Vamistor Screening Test. Three 191k ohm resistors (Date Code 7230) which had been subjected to the Vamistor screening (and rejected) were tested. After 72 hours of testing it was found that two resistors had increased appreciably in resistance (3.33 and 1.18 percent) with no change in the third. This result, though based on a small sample, indicates a large percentage of good parts are being rejected. This test was terminated because of the sample size.

(3) Testing of Resistors Submitted by Designers. Three samples of resistors, submitted by design engineers, were placed on nondestructive testing at 20 to 30 percent VR and +25 degrees C to obtain an indication of how the resistors which had been used on flight hardware performed. These samples were identified and the results were as follows:

(a) Stan Boyle Test - Twenty-four spare resistors of date codes suspected to have been used on flight equipment. This test has completed 2476 hours with eight defects. The mean drift of the 24 resistors is 1.26 percent with a maximum drifter of 20.31 percent. As shown by the mean drift of the eight defects in table 15, the drift rate decreases with time. This test is continuing.

(b) Watt-Hour Meter - Eleven resistors which had been removed from flight hardware after 1500 hours of operation. After 2494 hours of testing, only one resistor, S/N 292, a 33.2K ohm date code

Table 15. Defects From Stan Boyle Test

S/N	Initial Reading (Ohms)	Date Code	$\Delta R\%$ 20 Hrs.	$\Delta R\%$ 112 Hrs	$\Delta R\%$ 226 Hrs.	$\Delta R\%$ 423 Hrs.	$\Delta R\%$ 864 Hrs.	$\Delta R\%$ 1843 Hrs.	$\Delta R\%$ 2476 Hrs.
101	199.8 K	7150	0.045	0.025	0.250	0.350	1.902	2.352	2.452
105	42.21K	7132	0.118	0.308	0.474	0.640	0.924	1.066	1.113
108	42.15K	7132	0.047	0.166	0.474	0.546	0.641	0.664	0.664
110	42.32K	7132	0.024	0.095	0.378	1.181	1.985	2.410	2.528
112	42.13K	7132	0.000	0.142	0.475	0.854	1.780	1.946	2.018
114	20.02K	7134	0.000	0.000	0.000	0.050	0.100	0.300	0.350
120	20.06K	7134	0.100	0.100	0.199	0.249	0.349	0.449	0.548
123	20.04K	7134	1.148	3.643	5.289	7.535	10.479	16.567	20.309
MEAN DRIFT			0.185	0.56	0.94	1.42	2.27	3.219	3.704

7024, is above the 0.2 percent criteria. S/N 292 has increased approximately 22 percent above its initial reading of 33.49K. The highest drift among the other 10 resistors, which are relatively stable, is S/N 289 at 0.004 percent. This test is continuing.

(c) TV ISO - Six spare, 10k ohms resistors, date code 7123, that were to be installed in a TV ISO circuit. Prior to nondestructive stress testing these resistors had been operated for 57 hours at 25 percent VR and +25 degrees C. During nondestructive testing at 20 to 30 percent VR and +25 degrees C, these resistors have operated 1939 hours with no increase in resistance. This test is continuing.

(4) Nonhermetically Sealed Resistor Test. To determine if the nonhermetically sealed Vamistor resistors were susceptible to the same failure mechanism as the hermetically sealed Vamistor resistors, 128 RNR55J nonhermetics were subjected to 20 to 30 percent VR at +25 degrees C. After 197 hours of testing, no defects (0.2 percent criteria) or sustained drifters were produced. This test was terminated.

(5) MEPCO Resistor Test. To determine whether or not hermetically sealed MEPCO resistors were susceptible to the same failure mechanism as the Vamistor resistors, 55 of the glass encased type MEPCO's were placed on nondestructive stress testing. The test was conducted at +25 degrees C and 20 to 30 percent VR for 795 hours. The resistors did not demonstrate the sustained increase in resistance with time that is being found in similar tests on Vamistor resistors. Two resistors did fluctuate about the 0.2 percent drift criteria during alternate readings. This could be attributed to error in reading equipment and in handling techniques, since resistors were measured 16 times. This test has been terminated.

(6) Ward Leonard Resistor Test. Twenty hermetically sealed Ward Leonard resistors were subjected to nondestructive stress testing to determine if they displayed the same drift characteristics as the Vamistor resistors. The test was conducted at +25 degrees C and 20 to 30 percent VR. This test was conducted for 849 hours with no resistor showing greater than 0.03 percent drift. This small amount of drift could be attributed to error in reading equipment and handling technique, since the resistors have been measured nine times. This test has been terminated.

(7) AC-DC Test. To determine if the increase in resistance was ac and/or dc dependent, 100 RNR55C Vamistor resistors with five date codes covering the resistance range from 1K to 50K, were subjected to the following test.

Step 1: 16 hrs burn-in at 0.2 VR (ac RMS)
Step 2: 16 hrs burn-in at 0.2 VR (dc)
Step 3: 65 hrs burn-in at 0.2 VR (ac RMS)
Step 4: 17 hrs burn-in at 0.2 VR (dc)

The results of the test were as follows:

Step 1: Zero defects with a maximum drifter of 0.04 percent.

Step 2: 41 defects with a maximum drifter of 14 percent. The average drift of the 41 resistors exceeding the 0.2 percent defect criteria was 2.6 percent.

Step 3: Zero new defects and a 0.02 percent decrease in the mean drift of the population.

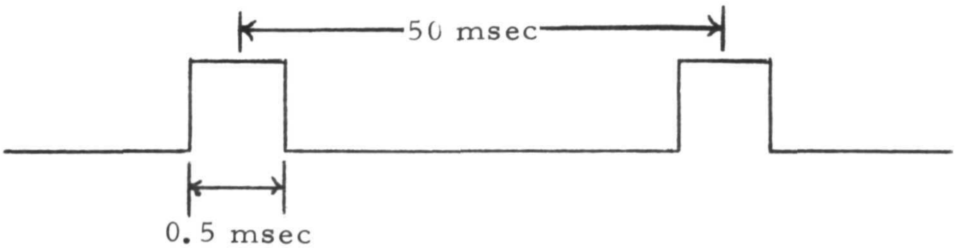
Step 4: 5 new defects and a maximum drifter of 16 percent. The mean drift of the population increased by 0.74 percent.

It was concluded from the results of this test that the RNR55C resistors tested were significantly more affected by application of 0.2 percent VR dc than 0.2 percent VR ac RMS voltage. Since all five date codes tested had at least one failure, it was concluded that no date code was free from this failure mechanism. Test data on the resistance ranges also indicated that no value tested was free from this failure mechanism. This test has been terminated. See results of related tests in Appendix A, Section V, Paragraphs A.3 and B.5.b and c.

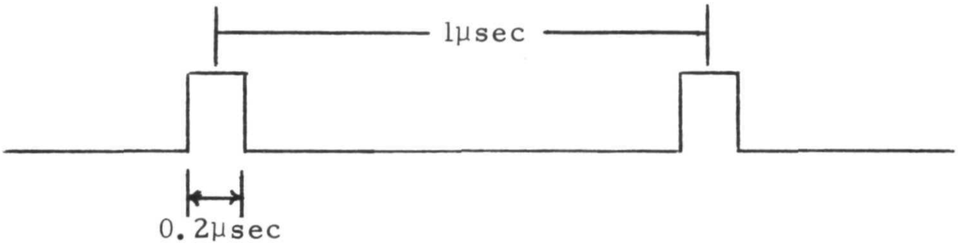
(8) DC Pulse Test. Nondestructive stress testing was conducted on 50 resistors to determine if a dc pulse had the same effect as a constantly applied dc voltage. Figure 19 shows the pulses which were used at 20 to 30 percent VR and +25 degrees C. After 2465 hours of testing, two resistors have exceeded 0.2 percent drift with a drift of 1.055 and 0.404 percent. This test is continuing. See results of pulsating dc test in Appendix A, Section V, Paragraph B.5.d.

(9) AC Test. Nondestructive stress testing was conducted on 50 resistors at 20 to 30 percent VR ac RMS to determine if ac alone had the same effect on the resistors as dc alone. After 2142 hours of testing no resistor has drifted greater than 0.2 percent. The maximum drift is 0.02 percent and the mean drift of the 50 resistors is 0.01 percent. This test is continuing. See results of related tests in Appendix A, Section V, Paragraph A.3 and B.5.b and c.

b. Data Analysis of Test Outside of Matrix. Nondestructive stress testing was conducted on 200 Vamistor resistors to determine if applied voltages, exceeding the rated voltage of the resistor, would cause the drift previously observed in Vamistor resistors. The tests were conducted at +25 degrees C with the following results.



(a) 20 Hertz (Hz) or 10 percent duty cycle, 7.5 volts applied to 7.15K, 9.09K, and 11.5K resistors.



(b) 10 Hz or 20 percent duty cycle, 5 volts applied to 3.74K and 5.76K resistors.

Figure 19. DC Pulse Chart

(1) Test Cell 71A. Fifty resistors at 125 percent VR. After 1586 hours of testing 5 resistors have exceeded 0.2 percent drift, with a maximum drifter of 5.42 percent. This test is continuing.

(2) Test Cell 71B. Fifty resistors at 150 percent VR. After 1586 hours of testing one resistor has exceeded 0.2 percent drift, with a drift of 0.92 percent. This test is continuing.

(3) Test Cell 71C. Fifty resistors at 175 percent VR. After 1586 hours of testing one resistor has exceeded 0.2 percent drift, with a drift of 0.26 percent. This test is continuing.

(4) Test Cell 71D. Fifty resistors at 200 percent VR. After 1586 hours of testing 4 resistors have exceeded 0.2 percent drift, with a maximum drifter of 1.98 percent. This test is continuing.

Nondestructive stress testing was also conducted on 50 resistors at -40 degrees C and 20 to 30 percent VR (Test Cell 77A), to better determine the effect on the failure mechanism at extremely cold temperatures. After 1964 hours of testing, 10 resistors have exceeded 0.2 percent drift, with a maximum drifter of 2.50 percent. This test is continuing.

c. Nondestructive Stress Testing of Resistors Removed From Hardware. The following nondestructive stress testing was performed on resistors that had been removed from Skylab digital system hardware:

(1) Test Operation. A total of 254 Vamistor resistors were removed from the WCIU and ATMDC. The units from which they were removed, operating hours, quantity removed from each unit, and percentage of those removed that were out of tolerance are listed in table 16.

Table 16. Vamistor Resistors Removed From Skylab Hardware

Unit	Unit Operate Hours	Quantity Removed	Percent Over Tolerance
WCIU 1	2860*	144	7.65
WCIU 3	915	81	3.7
ATMDC 4	783	29	3.4
		254	

*5720 for common section parts

Each resistor that was removed was given two unique serial numbers, part and page serial numbers, reference designator, and mounting orientation. From this data, the operating temperature, electrical application, polarity, resistance value, wattage, tolerance, and operating time of each resistor could be determined. The resistance of each was measured after removal and values recorded. Of the total removed, 16 were out of tolerance on the high side (see table 17). Of the 16 that were out of tolerance, 15 were 0.1 percent and one was a 1.0 percent tolerance resistor. A 3880 ohm, 0.1 percent, 0.1 watt resistor was the greatest drifter, measuring 1.0 percent above nominal resistance.

The resistors removed from Skylab hardware were divided into 4 groups (see table 18). One group of 22 was a lab test sample; one group of 118 was placed on test at 20 to 30 percent VR at 25 degrees C; a group of 56 was placed on test at 25 degrees C and at the respective voltages applied in the hardware from which they were removed; and the balance were held. The test groups had both in and out of tolerance resistors. The purpose of Group A was to determine if resistors could be forced to drift by placing them on test under what appeared to be worst case conditions, regardless of unit application. The purpose of Group B was to prove that resistors would not start to drift if they had not drifted during the time they had been in the hardware (783 to 5720 hours). The lab test samples were used for metallurgical and chemical investigation into the failure mechanism. (See paragraph A.2.b, entitled Wet Chemical Analysis, in this section.) Subsequent testing indicated that a leak test evaluation should be performed and 21 of the parts on hold were selected for evaluation.

Table 17. Production Hardware Analysis of Vamistor Resistors From WCIU S/N 1, 3, and ATMDC S/N 4

Serialized Item No.	Part Number	Nom Spec Value	Tolerance Percent	Date Code	Meas. Value (Ohms)	Δ tolerance Amount Over Initial Design Tolerance (Percent)	Δ Tol. E. O. L. Amount Over E. O. L. Tol.	Ckt Allowable Drift* (Percent)	Location	Operating Hours	APPLICATION Percent VR	Worse Case Temp.	Test Matrix Cell No.	AC/DC
373	RNR55C3881BP	3.88K	0.1	7019	3.8855K	0.04	Within	22	WCIU-1	2860	10-14	C(32)	31	DC
377	RNR55C3881BP	3.88K	0.1	7019	3.8954K	0.29	Within	22	WCIU-1	2860	10-14	C(31)	31	DC
379	RNR55C3881BP	3.88K	0.1	7019	2.8916K	0.13	Within	22	WCIU-1	2860	10-14	C(31)	31	DC
346	RNR55C4021BP	4.02K	0.1	7021	4.0255K	0.03	Within	22	WCIU-1	2860	10-14	C(32)	31	DC
349	RNR55C3881BP	3.88K	0.1	7019	3.8921K	0.21	Within	22	WCIU-1	2860	10-14	C(31)	31	DC
452	RNR60E5111BP	5.11K	0.1	7017	5.1181K	0.06	Within	> 100	WCIU-1	2860	0.1-0.9	C(29)	10	DC
453	RNR60E2941BP	2.94K	0.1	7015	2.9608K	0.61	Within	3.1	WCIU-1	2860	15-19	C(29)	38	DC
445	RNR60E5111BP	5.11K	0.1	7017	5.1169K	0.04	Within	> 100	WCIU-1	2860	0.1-0.9	C(29)	10	DC
446	RNR60E5111BP	5.11K	0.1	7017	5.1167K	0.03	Within	> 100	WCIU-1	2860	1-4	C(31)	17	DC
493	RNR60E5111BP	5.11K	0.1	7017	5.1172K	0.04	Within	> 100	WCIU-1	5720	1-4	C(29)	17	DC
494	RNR60E5111BP	5.11K	0.1	7017	5.1157K	0.01	Within	>100	WCIU-1	5720	1-4	C(29)	17	DC
473	RNR55C3881BP	3.88K	0.1	7019	3.9200K	0.90	Within	22	WCIU-3	458	10-14	C(31)	31	DC
006	RNR60E5111BP	5.11K	0.1	7017	5.1172K	0.04	Within	>100	WCIU-3	458	1-4	C(32)	17	DC
039	RNR60E5111BP	5.11K	0.1	7017	5.1185K	0.07	Within	>100	WCIU-3	915	1-4	C(29)	17	DC
013	RNR60E5111BP	5.11K	0.1	7017	5.1162K	0.02	Within	>100	WCIU-3	915	1-4	C(29)	17	DC
265	RNR60E1002FP	10 K	1.0	7016	10.1360K	0.36	Within	3	ATMDC-4	783	20-38	C(33)	45	DC

NOTE: *Based on acceptance test criteria.

Table 18. Test Matrix for Parts Removed From Hardware

Test	Total Parts	Condition When Removed	
		Number Parts In Tolerance	Number of Parts Out of Tolerance
Chem/Met	22	16	6
Group A 0.2 to 0.3 VR, 25°C	118	112	6
Group B Application Voltage at 25°C	56	52	4
Leak Test	21	21	0

(2) Results of Test. A change in resistance equal to or greater than +0.2 percent was used as the defect criteria in this test. As shown in table 19, the resistors placed on test at 20 to 30 percent VR and 25 degrees C (group A) showed evidence of drift after 13 hours of test. Two of the 118 showed drift of greater than 0.2 percent. At the end of 75 hours, 7 resistors of the 118 showed drift of greater than 0.2 percent. At the 219 hour point, 8 parts of the 118 showed drift of greater than 0.2 percent. The drift of each of the 8 resistors was equal to or greater than its design tolerance. Two resistors, (S/N 473 and S/N 27) were removed from test for special analysis aimed at determining if the drift was caused by seal leakage. The results of that analysis is given in paragraph A.2.d (Failure Analysis) in this section. Two of the 8 defects (S/N 377 and 473) were out of tolerance when removed from the hardware.

The resistors placed on test at the hardware application voltage and 25 degrees C showed evidence of drift after 13 and 87 hours of test but no defects, as shown in table 20. After 231 hours of test, 3 resistors exhibited greater than +0.2 percent drift and after 631 hours, 4 resistors showed drift of greater than plus 0.2 percent. These resistors were in test at 20 to 30 percent VR and 25 degrees C. One of the 4 (S/N 265) had been out of tolerance when removed from the hardware.

d. Catastrophic Failures in Nondestructive Stress Testing. Nine resistors have opened under stress during the nondestructive test program. A brief history of each failed resistor is presented in the following paragraphs:

(1) Resistor Number 1, RNR55C9532FP, Date Code 7141. Resistor number 1 was given to the test program by Stan Boyle, S&E-ASTR-EAA. It had been installed on a PC board and, after removal therefrom, was submitted (with 240 other resistors) for utilization in the test program. Each of the resistors was subjected to a gross seal leak test, using the Radiflo test

Table 19. Group A Drifters

Unit	Ref. Des.	Page	Part Serial Number	Value		Voltage			Initial Resistance (Ohms)	Design Tol. (%)	Δ From Initial Resistance			
				R Nominal (Ohms)	Power Rating (Watts)	Hardware Application % of VR	Test % of VR	Rated (Volts)			ΔR% 13 Hr.	ΔR% 75 Hr.	ΔR% 219 Hr.	ΔR% 599 Hr.
WCIU 3	R41	051	473	3.88 K	0.1	11.3	25	19.5	3.9194 K	0.1	6.2	10.1	* > 12	* > 12
WCIU 1	R44	051	377	3.88 K	0.1	11.3	25	19.5	3.8945 K	0.1	0.009	0.44	0.9	1.5
WCIU 3	R25	051	460	4.99 K	0.1	0.4	26	22.4	4.9944 K	1.0	0.02	0.23	1.0	1.6
WCIU 1	R21	051	348	24 K	0.1	18	30	49	23.993 K	0.1	0.18	1.3	2.5	2.7
WCIU 3	R28	029	27	26.7 K	0.125	1.7	25	58	26.741 K	1.0	3.9	7.9	* > 13	* > 13
WCIU 1	R5	047	304	20 K	0.125	1.2	30	50	19.992 K	1.0	0.13	1.04	1.2	1.24
WCIU 3	R43	051	469	3.88 K	0.1	11.3	25	19.5	3.8828 K	0.1	0.15	0.96	1.8	2.56
WCIU 1	R45	051	351	3.88 K	0.1	11.3	25	19.5	3.8836 K	0.1	0.0	0.03	0.2	0.42

*Removed from Test at 99 hours.

Table 20. Group B Drifters

Unit	Ref. Des.	Page	Part Serial Number	Value		Voltage			Initial Resistance (Ohms)	Design Tol. (%)	Δ From Initial Resistance			
				R Nominal (Ohms)	Power Rating (Watts)	Hardware Application % of VR	Test % of VR	Rated (Volts)			ΔR % 13 Hrs.	ΔR % 87 Hrs.	ΔR % 231 Hrs.	ΔR % 631 Hrs.
WCIU 1	R30	051	341	24 K	0.1	18	20	49	23.984 K	0.1	0.054	0.20	0.91	0.93
WCIU 3	R26	051	461	24 K	0.1	18	20	49	24.015 K	0.1	0.054	0.154	0.3	0.23
WCIU 1	R21	051	376	24 K	0.1	18	20	49	23.998 K	0.1	0.0	0.088	0.19	0.21
ATMDC 4	R15	770	265	10 K	0.125	33	29	34.6	10.132 K	1.0	0.05	0.14	0.34	3.0

method, and 7 leakers were found. The seven leakers were then subjected to a low voltage burn-in test of approximately 25 percent VR at ambient temperature. The initial resistance reading of resistor number 1 (one of the seven leakers) was 95.53K ohms; 177.64 K ohms after 51 hours of test (85.85 percent drift); and measured open after 288 hours of test.

(2) Resistor Number 2, RNR55C6812FR, Date Code 7123. Resistor number 2 was subjected to 10 percent VR at ambient temperature (test 31B). This resistor, initially, measured 68.196K ohms; 68.411K ohms after 46 hours of test (0.556 percent drift); 79.888K ohms after 636 hours (17.15 percent drift); and was open when measured after 804 hours of testing.

(3) Resistor Number 3, RNR55C4992FP, Date Code 7234. Resistor number 3 was one of those in the ambient group III test of the 45A test cell, all of which were from MSFC stock. These resistors were subjected to 25 percent of VR at ambient temperature. Resistor number 3, initially, measured 49.83K ohms; 51.53K ohms (3.412 percent drift) after 12 hours (at R_{17}); after 717 hours of testing, it measured 83.59K ohms (67.75 percent drift); and it was open at the R_{18} reading after 868 hours.

(4) Resistor Number 4, RNR55C4992FR, Date Code 7134. Resistor number 4 was from MSFC stock, but had been subjected to 100 degrees stress without voltage, in previous stress testing, for 100 hours with no drift. This resistor was subjected to 20 to 30 percent of VR at ambient temperature (test 45 I). The initial resistance reading was 49.829K ohms; 50.687K ohms (1.722 percent drift) after 12 hours of test; 52.326K ohms (5.01 percent drift) after 432 hours; and open when measured after 548 hours of testing.

(5) Resistor Number 5, RNR55C3881BP, Date Code 7019. Resistor number 5 is one of 118 removed from WCIU S/N 1 and 3 and the ATMDC S/N 4 power supply at IBM. It was subjected to 20 to 30 percent of VR at ambient temperature (test 45L). Resistor number 5 was removed from circuitry of WCIU-3 where it had operated for 783 hours at 11.3 percent of VR. Prior to testing, the resistance measurement was 0.9 percent above nominal. It was a 0.1 percent tolerance resistor. Initially, the resistor measured 3.919K ohms; 4.161K ohms after 13 hours (6.175 percent drift); and 4.395K ohms (12.146 percent drift) after 99 hours. After 99 hours, the resistor was removed from test and baked for 48 hours at 105 degrees C (in a nitrogen atmosphere), vacuum baked for an additional 2 hours, and then vorite coated. The voltage was reapplied and, after 108 hours of testing, the resistance measured 5.1545K ohms (32.5 percent drift) and was open after 191 hours of testing.

(6) Resistor Number 6, RNR65C1004FP, Date Code 7212. Resistor number 6 was from MSFC stock (test 45 0). It was subjected to 25 percent VR at ambient temperature. Initially, this resistor measured 1000.2K

ohms; 1112.6K ohms after 48 hours of testing (2.369 percent drift); 1336.3K ohms after 201 hours (33.603 percent drift); and was open after 338 hours of test.

(7) <u>Resistor Number 7, RNR65C3013FP, Date Code 7026.</u> Resistor number 7 was from MSFC stock (test 45 0). Initially, the resistance measured 301.5K ohms; 656.9K ohms after 48 hours (117.877 percent drift); and was open after 137 hours of testing. The resistor was subjected to 20 to 30 percent VR at ambient temperature.

(8) <u>Resistor Number 8, RNR65C3013FP, Date Code 7026.</u> Resistor number 8 was from MSFC stock (test 45 0). Initially, the resistance measured 300.2K ohms and was open at the R_2 measurement. This test was conducted at 20 to 30 percent VR and ambient temperature.

(9) <u>Resistor Number 9, RNR55C2002FP, Date Code 7235.</u> Resistor number 9 was from MSFC stock (test 52 A). In this test the resistor was subjected to 60 to 70 percent of VR at ambient temperature. Initially the resistance measured 19.9K ohms; 20.66K ohms after 17 hours (3.6 percent drift); 45.74K ohms after 566 hours at R_{16} (129.377 percent drift); and was open at R_{17} after 703 hours of testing.

The above data indicates that in each case, where the resistors were subjected to at least 15 percent of VR at a temperature of 25 degrees C, they were early drifters (greater than 2 percent) prior to catastrophic failure. In the case of resistors operated at stresses below the above conditions the drift mechanism is decreased such that the above statement is not applicable.

Table 21 presents a summary of the above open resistors.

(10) <u>Resistor Number 10, RNR55C2002FP, Date Code 7150.</u> Resistor number 10 was from MSFC stock (test 37-B). This test was conducted at 15 percent VR and a temperature of 5 degrees C. The initial resistance was 199.83K ohms and increased to 209.74K ohms (5 percent increase) after 12 hours; 291.56K ohms (45.9 percent increase) after 294 hours; and open at 465 hours of testing.

(11) <u>Resistor Number 11, RNR55C4992FR, Date Code 7234.</u> Resistor number 11 was from MSFC stock but had been subjected to 100 dregres stress without voltage, in previous stress testing, for 100 hours with no drift. This resistor was subjected to 20 to 30 percent of VR at ambient temperature. The initial resistance reading was 49.66K ohms and increased to 51.205K ohms (3.1 percent increase) after 12 hours; 80.57K ohms (62.23 percent increase) after 1218 hours;and open after 1486 hours of testing.

Table 21. Catastrophic Failures in Nondestructive Stress Testing

S/N	Date Code	Test Matrix Cell Number	Drift Prior To Open (Percent)	Time To Open (Hours)	Resistor Value (Ohms)
MSFC	7141	Leaker Test	85.85	51-288	95.3K
457	7123	31B	17.15	636-804	68.1K
158	7234	45A	67.75	156-231	49.9K
286	7234	45I	5.01	432-548	49.9K
473	7019	45L	32.0	108-191	3.88K
5	7212	450	33.6	210-338	1000K
31	7026	450	117.0	48-137	301K
35	7026	450	-	0-48	301K
208	7235	52A	129.4	566-703	20K
6287	7150	37B	45.90	465	200K
287	7234	45I	62.23	1218-1486	49.9K
202	7235	45E	128.86	1502-1833	22K
159	7234	45A	117.08	1519-1847	49.9K
156	7234	45A	189.03	1519-1847	49.9K
6322	7146	46B	72.80	966-1302	31.1K
155	7234	45A	145.94	2176-2500	49.9K
20	7215	Screened Vamistor	0.009	802-1130	200K

(12) Resistor Number 12, RNR55C2212FR, Date Code 7235. Resistor number 12 was from MSFC stock (test 45E). This test was conducted at 20 to 30 percent VR and a temperature of 25 degrees C. This resistor initially measured 21.9K ohms and increased to 23.08K ohms (5.4 percent increase) after 17 hours; 50.12K ohms (128.86 percent increase) after 1505 hours;and open when measured after 1833 hours of testing.

(13) Resistor Number 13, RNR55C4992FR, Date Code 7234. Resistor number 13 was one of the resistors in the ambient group III test of the 45A test cell, all of which were from MSFC stock. These resistors were subjected to 25 percent of VR at ambient temperature. Resistor number 13 initially measured 49.63K ohms and increased to 51.07K ohms (2.90 percent increase) at 12 hours; 107.74K ohms (117.08 percent increase) after 1519 hours and open after 1847 hours of testing.

(14) Resistor number 14, RNR55C4992FR, Date Code 7234. Resistor number 14 was from MSFC stock and tested in the 45A test cell as described above. Initially this resistor read 49.88K ohms and increased to 51.61K ohms (3.50 percent increase) after 12 hours; 144.17K ohms (189.03 percent increase) after 1519 hours;and open after 1847 hours of testing.

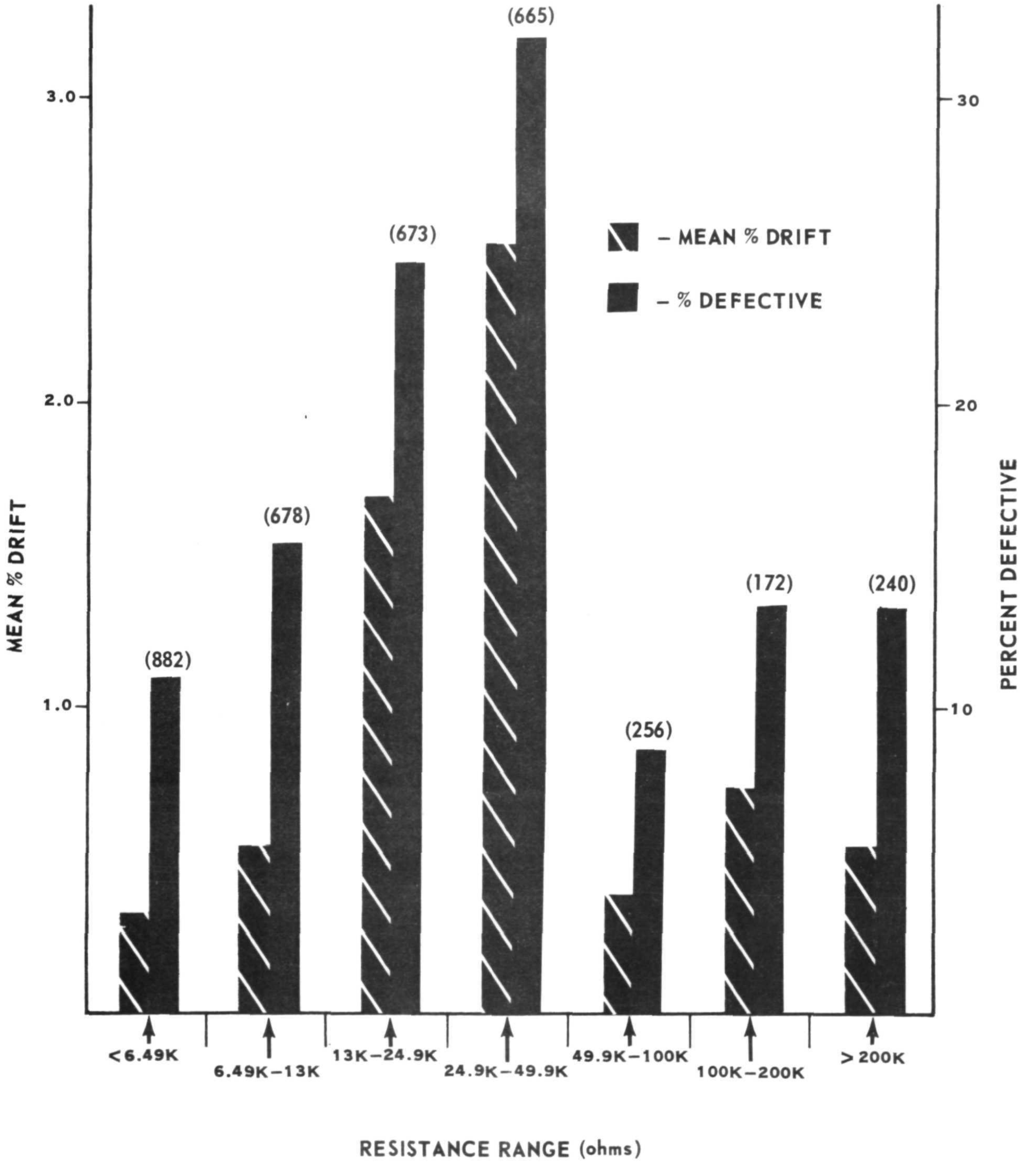
(15) <u>Resistor Number 15, RNR 70C3322FP, Date Code 7146.</u> Resistor number 15 was from MSFC stock (test 46B). This test was conducted at 20 to 30 percent VR and a temperature of 50 degrees C. The initial resistance was 33.15K ohms and increased to 37.17K ohms (12.12 percent increase) after 12 hours; 57.28K ohms (72.81 percent increase) after 966 hours;and open after 1302 hours of testing.

(16) <u>Resistor Number 16, RNR55C4992FR, Date Code 7234.</u> Resistor number 14 was from MSFC stock and tested in the 45A cell at 25 percent of VR and ambient temperature. The resistance initially measured 49.85K ohms and increased to 50.95K ohms (2.2 percent increase) after 12 hours; 122.6K ohms (145.94 percent increase) after 2176 hours;and open after 2500 hours of testing.

(17) <u>Resistor Number 17, RNR55C2003FM, Date Code 7251.</u> Resistor number 17 was a lot of 100 resistors which had been manufactured by Vamistor using the new boiling wash technique. These resistors had passed the newly installed Vamistor burn-in (screening). In the stress testing they were subjected to 20 to 30 percent VR at ambient temperature. Resistor 17 initially read 198.81 and increased to 199.06 (0.001 percent increase) after 151 hours; 200.6K ohms (0.009 percent increase) after 802 hours;and open after 1130 hours of testing. It is obvious that this particular resistor did not display the drift tendency seen in similar Vamistor resistors. Therefore, it can be safely assumed that the failure of this resistor could have been caused by a failure mechanism other than the one noticed in similar Vamistor resistors.

e. <u>Data Analysis of Test Matrix Results.</u> The data collected from the nondestructive testing of approximately 5000 resistors were analyzed statistically for trends and inferences. Some unexplained anomalies were observed in the test data which were attributed to numerous interdependent drift causing variables in each resistor. The following analyses of results have excluded these anomalies so that accurate, unbiased conclusions could be reached.

(1) <u>Resistance Range.</u> The resistors were divided into seven distinct resistance ranges. Each resistance range was not necessarily included in each test cell, but was selected such that each range had the same chance of being selected. When the data was analyzed the bar chart shown in figure 20 resulted. The analysis was independent of the voltage or temperature seen by the resistance ranges. As shown (all things being equal) the resistance range from 24.9K to 49.9K has demonstrated a higher percentage of defective resistors and a greater percentage of mean drift than the other resistance ranges tested; however, it is more important to note that no resistance range is free from defects. In addition, further analysis has also shown that no resistance value is free from defects.



NOTE: NUMBER ENCLOSED IN PARENTHESIS IS TOTAL NUMBER OF RESISTORS IN THE TEST.

Figure 20. Population % Drift and % Defective Versus Resistance Range (Under All Test Conditions)

(2) Date Code. The data collected on date codes tested were analyzed statistically using several techniques, such as weighting, normalization, etc.. None of these analyses produced a statistically satisfying correlation between drift and certain date codes. At first glance (figure 21) it would seem that date codes 7234 and 7235 have significantly more defects per total tested than the other date codes. A thourugh search of data revealed, however, that these date codes were, for the most part, tested under what has since been determined to be worst case conditions. Therefore, it is concluded that the failure mechanism is independent of date code..

(3) Applied Voltage. It was determined during testing, prior to the nondestructive stress tests conducted by MSFC, that the failure mechanism was exhibited when low level dc voltages (20 to 30 percent VR) were applied. Therefore, personnel at MSFC performed stress tests with this level of voltage and its surrounding values. The resulting data was analyzed in several ways. Two of these produced statistically satisfying correlations. Figure 22 shows that when the effect of the applied voltages is analyzed, at the worst case temperature conditions, the result is basically the same as when analyzed at all temperatures (see table 22). Based on these two analyses it can be stated that the drift is affected significantly more by applied voltages of 10 to 110 percent VR than 0.1 to 10 percent VR.

Table 22. Applied Voltages With Respect to all Temperatures Tested.

Applied Voltage % VR	Total Number Parts	% Defects	Mean % Drift
20 to 30	1247	30.15	1.94
50 to 70	215	23.72	1.85
15	379	24.54	1.41
80 to 110	208	20.67	0.67
10	384	15.36	0.59
5	375	6.40	0.21
0.1	378	1.59	0.09
1.0	380	1.32	0.03

NOTE: % Defects based on 0.2% defect criteria

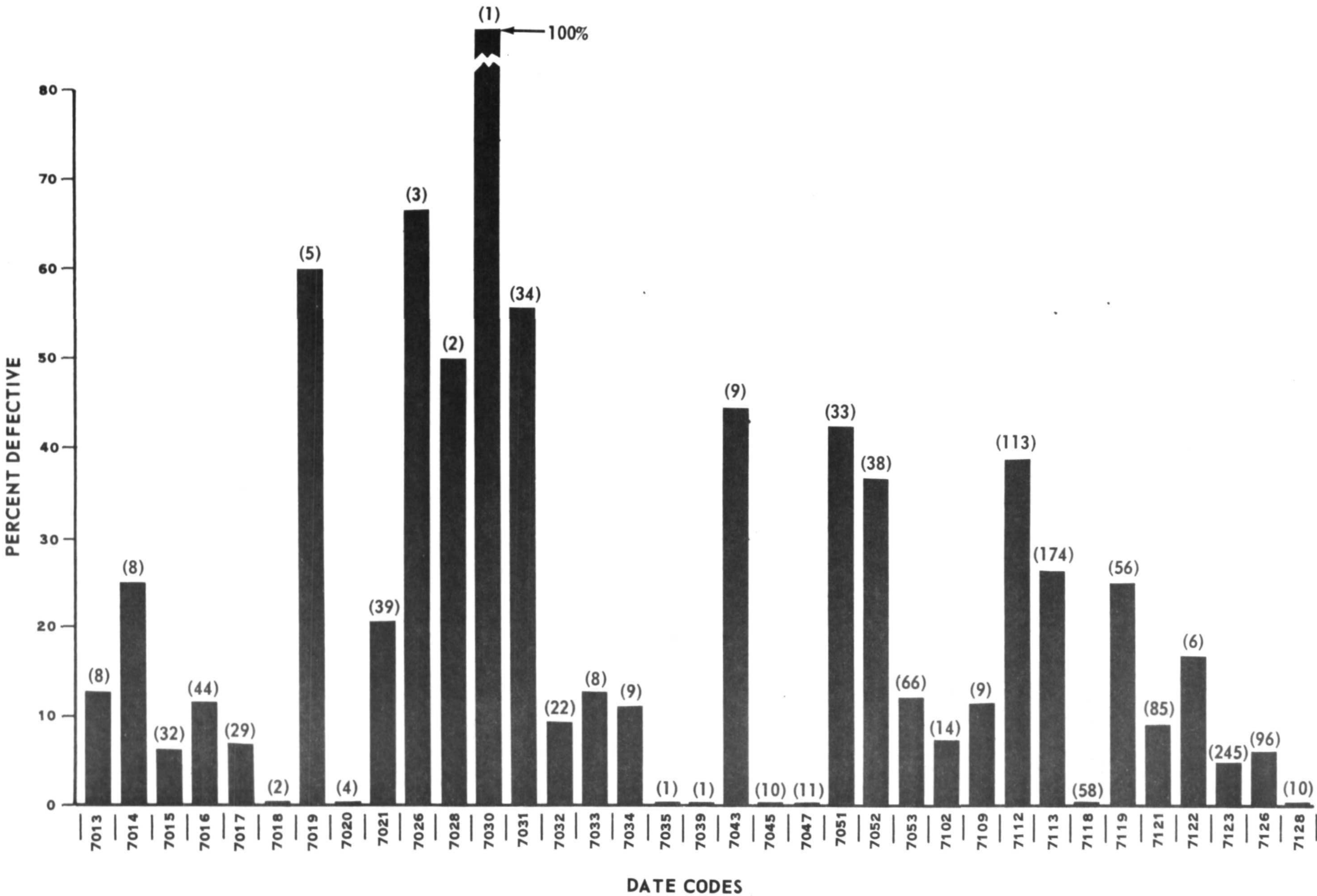


Figure 21. Percent Defective Versus Date Codes (Sheet 1 of 2)

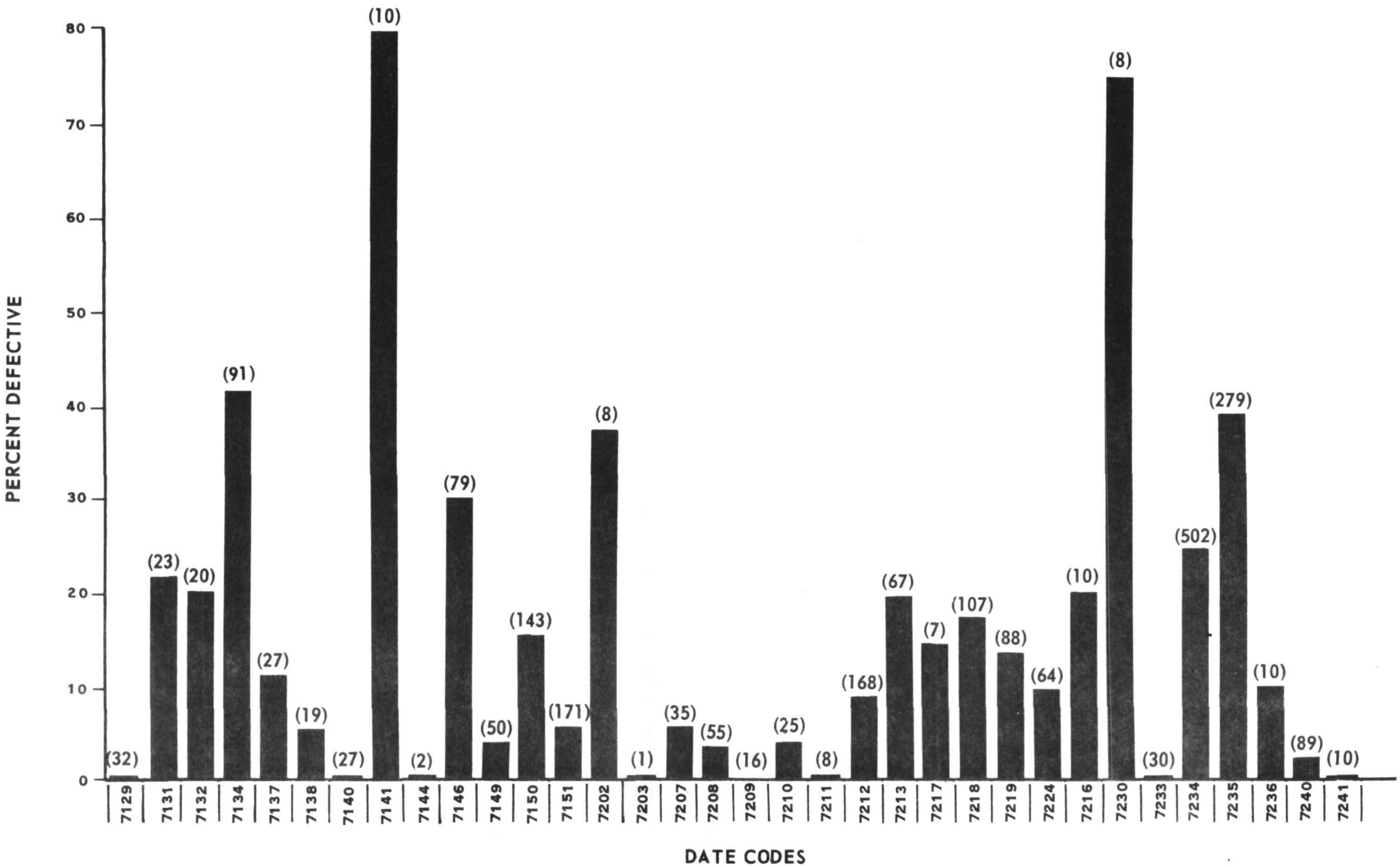


Figure 21. Percent Defective Versus Date Codes (Sheet 2 of 2)

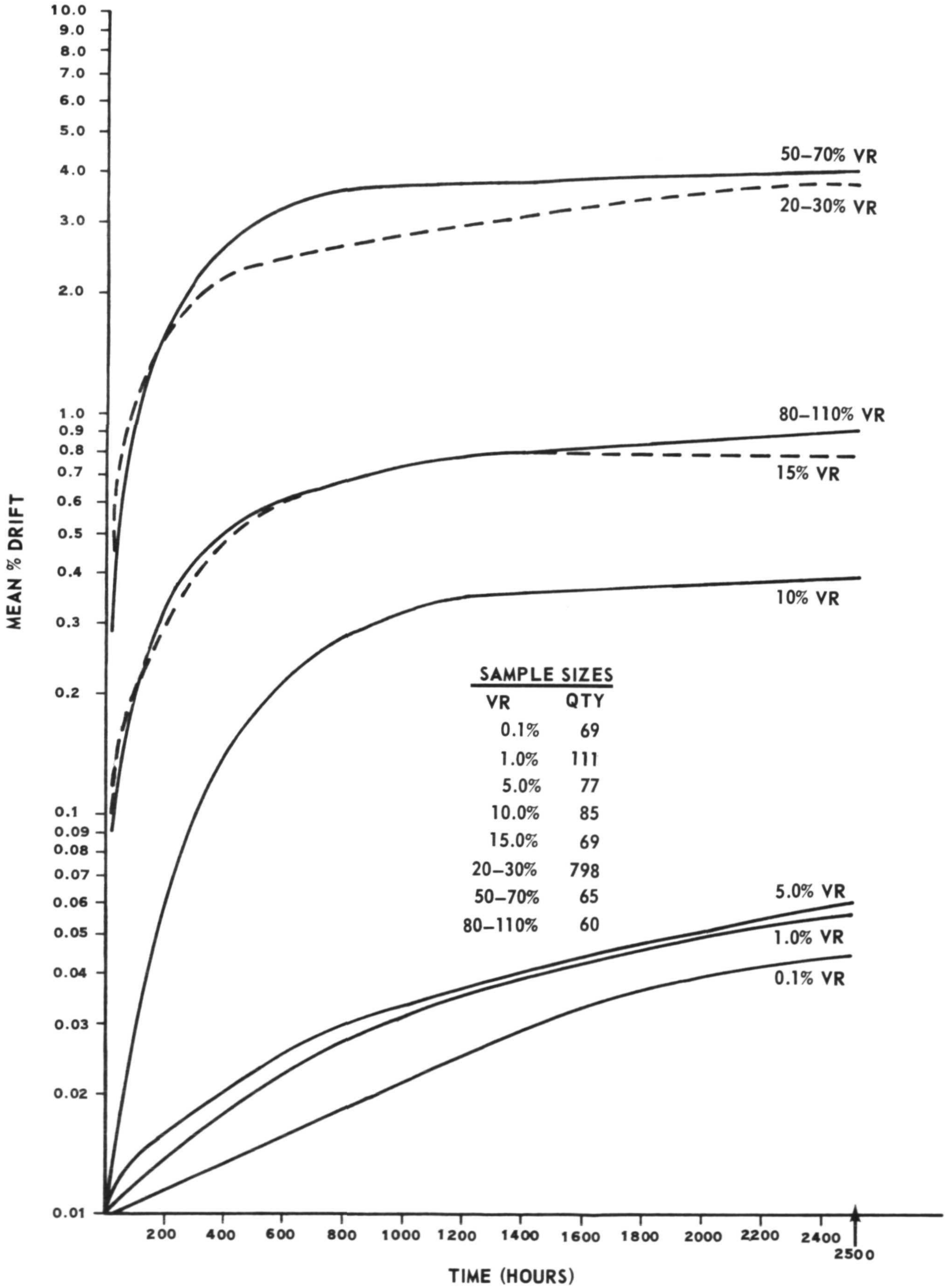


Figure 22. Applied Voltage Parameters, Mean % Drift Versus Time at 25 Degrees C.

(4) Temperature. Data was analyzed for statistical conclusions concerning temperature using similar techniques as for the applied voltage discussed in e.(3) above. The two methods that produced statistical correlations are presented in table 23 and figure 23. Based on these two analyses it can be stated that the drift is significantly more affected by 5 and 25 degrees C than by the other temperatures tested. When data was correlated, temperatures of minus 25 and plus 50 degrees C showed a tendency to have more of an effect than temperatures of 75, 100, and 125 degrees C. Further testing can better define this separation.

(5) Stabilization and Identidication of Drifters. The results of the data analysis conducted on stabilization of the drift rate of the resistors are shown in figures 22 and 23. These figures show that the drift rate definitely decreases at approximately 400 hours. Although these curves include both resistors that haven't crossed the 0.2 percent defect threshold and those that have, they proved to adequately represent the behavior of the defectives and gross drifters. This was proven by analyzing the drift rates of all resistors that drifted more than 0.2 percent, resistors that drifted more than 10 percent but not more than 20 percent, and of these drifting more than 20 percent. These analyses all attested to the stabilization of drift at approximately 400 hours.

Table 23. Temperatures With Respect to all Applied Voltages Tested.

Temperature Degrees C	Total Number Parts	% Defects	Mean % Drift
25	1334	25.94	1.82
5	529	28.17	1.59
-20	359	21.17	0.82
50	417	6.95	0.40
125	368	10.05	0.23
100	69	2.90	0.05
75	490	3.67	0.05
NOTE: % Defects based on 0.2% defect criteria			

Further analysis of data also showed that the greater percentage of resistors drifting more than 0.2 percent could be identified or seen prior to 200 hours. This analysis was later extended to encompass other defective thresholds (see figure 24). This was conclusive in showing that the drifters could be identified at 200 hours or less, depending on the threshold setting.

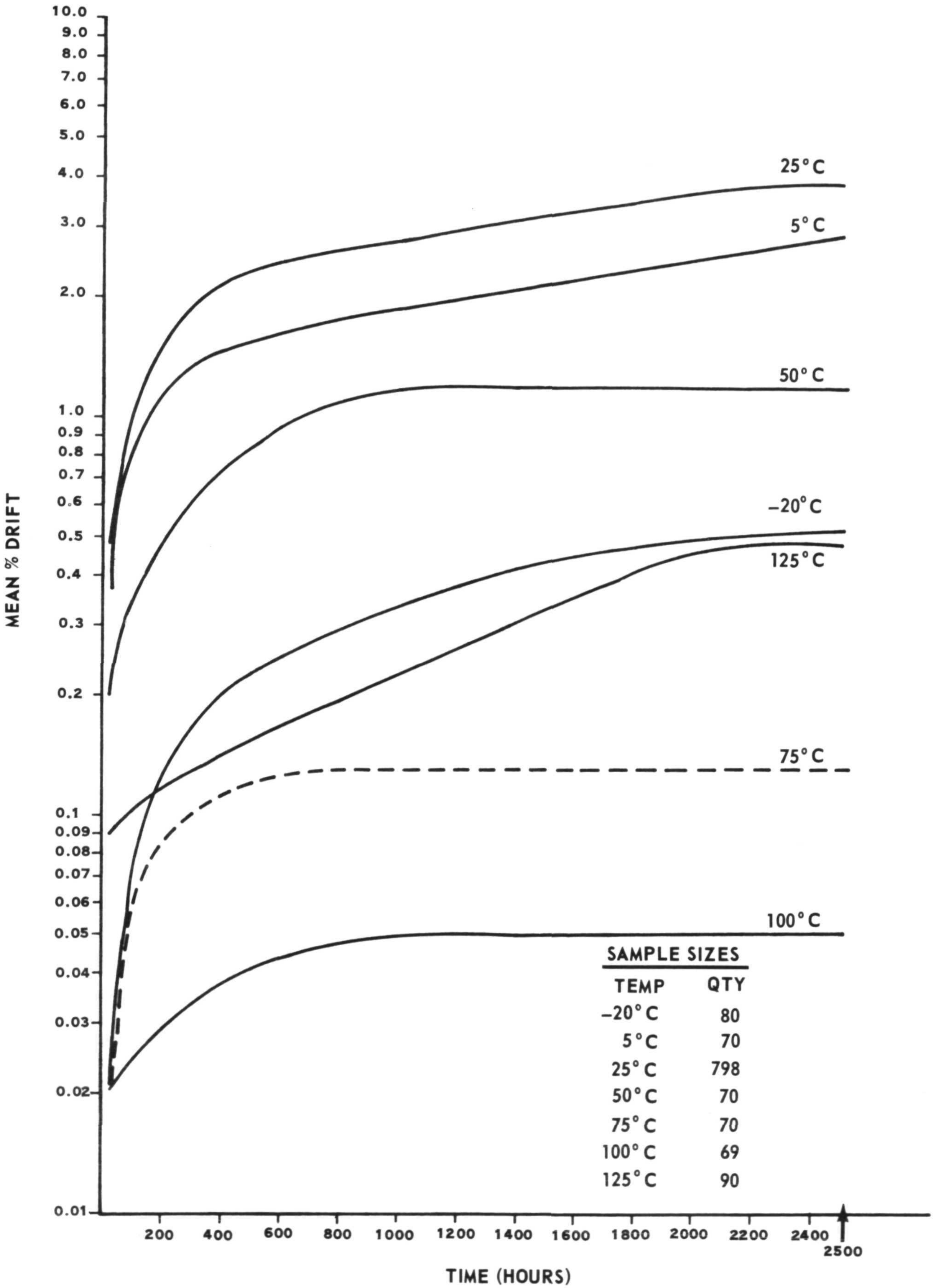


Figure 23. Temperature Parameters, Mean % Drift Versus Time at 20 to 30% VR

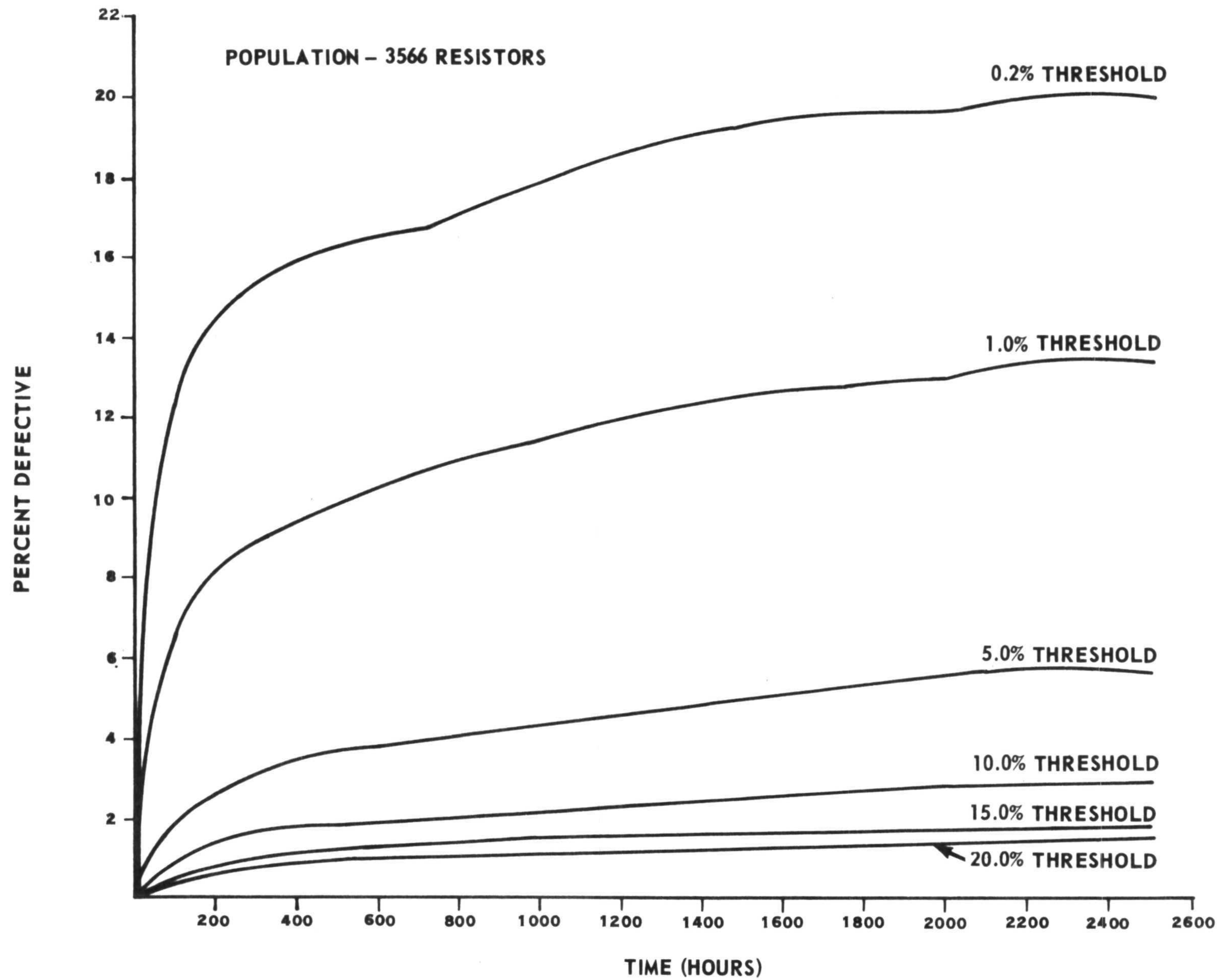


Figure 24. Cumulative Percent Population Crossing Defective Thresholds

APPENDIX A

INVESTIGATION OF DRIFT IN VAMISTOR THIN FILM RESISTORS

By

MATERIALS DIVISION
ASTRONAUTICS LABORATORY

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

LIST OF ILLUSTRATIONS (Continued)

LIST OF ILLUSTRATIONS (Continued

LIST OF TABLES

SECTION I. INTRODUCTION

On December 5, 1972, this division was initially advised of a problem concerning electrical drifting of resistors in Skylab hardware. Shortly thereafter an MSFC investigative team was established and this division was assigned lead responsibility for determining the mechanism responsible for the drift in resistor characteristics. This report describes the studies aimed at definition of the drift mechanism.

In order to understand the conditions prevailing at the point of manufacture of the resistors, a detailed study of the vendor's manufacturing process and materials was performed and is discussed in section II of this report. In section III, the microscopic and chemical analyses which identify the contaminants involved in the resistor drift mechanism are discussed. Section IV describes a more fundamental study which utilized electrolytic cells based on nichrome electrodes and a copper plating solution used in manufacture of the resistors. Section V contains a comprehensive study which discusses the effect of controlled contaminant levels, environments, and operating conditions of drift tendencies in test resistors.

A schematic of the internal design of the resistor is shown in figure 1.

A series of observations was made at the beginning of this study:

a. Initial microscopic studies on drifting resistors revealed a consistent pattern of disappearance of nichrome from the edge of the helical cut of groove illustrated by figures 2 and 3. This condition appeared during applications of low-level dc voltage (20 to 30 percent of rated voltage) through the resistor. A directional effect was observed in the nichrome erosion following dc voltage application, also observable in figure 3.

b. A preliminary survey of the pertinent literature dealing with metal film resistor failure mechanisms quickly points out the dangers of residual contamination in the form of ionic, current-carrying species and water, coupled with voltage application. This condition leads to electrolytic removal of the thin film resistance element with an increase in resistance value.

c. Discussions with Vamistor personnel revealed that, in their opinion, varying concentrations of plating solution residue could have been inadvertently left in the resistors as a result of variations in the post plating rinse procedure.

These observations are all explainable by electrochemical dissolution of the nichrome, leading to decreased cross-section areas and higher

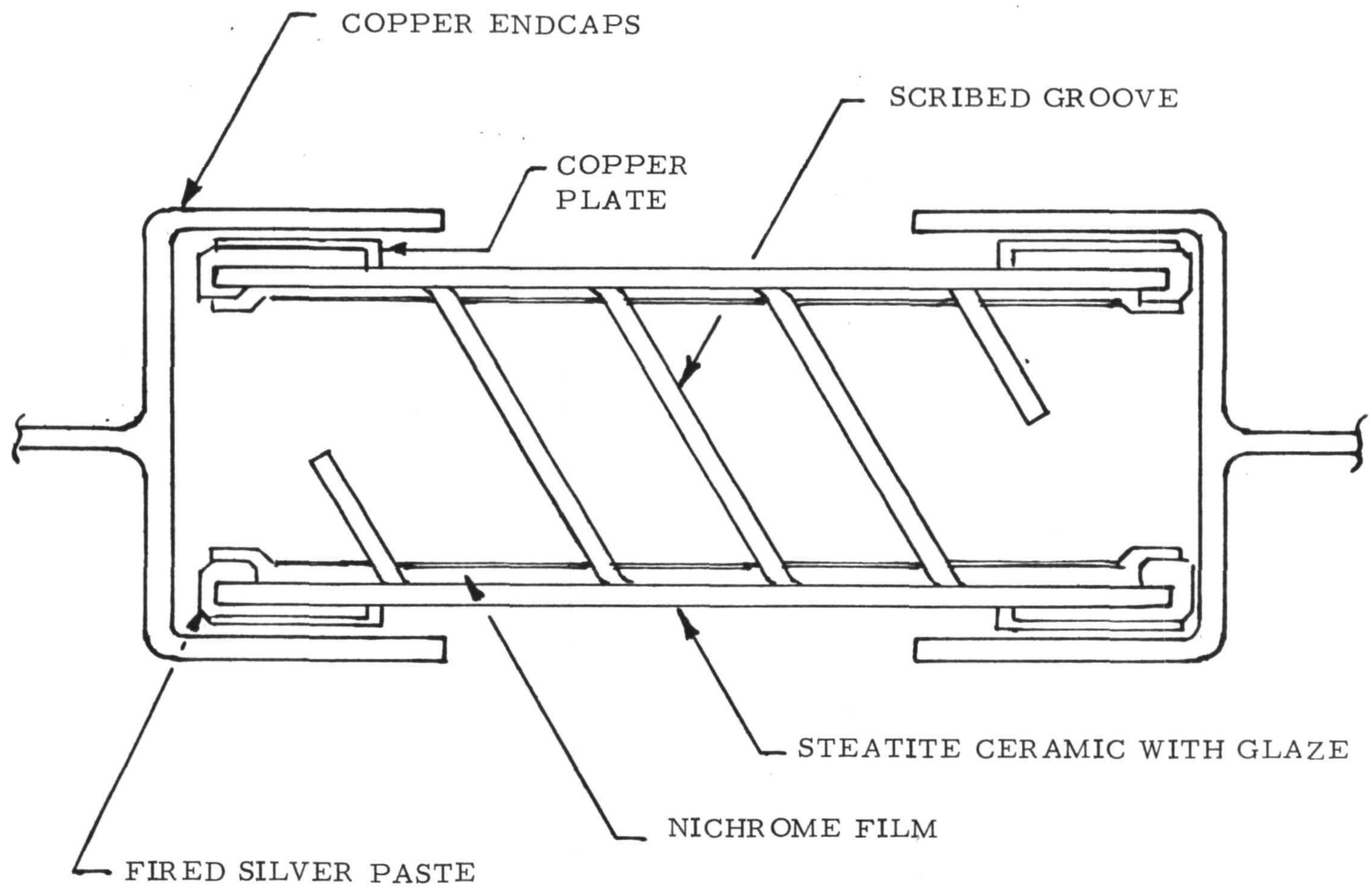


Figure 1. Internal Design of Vamistor Resistor

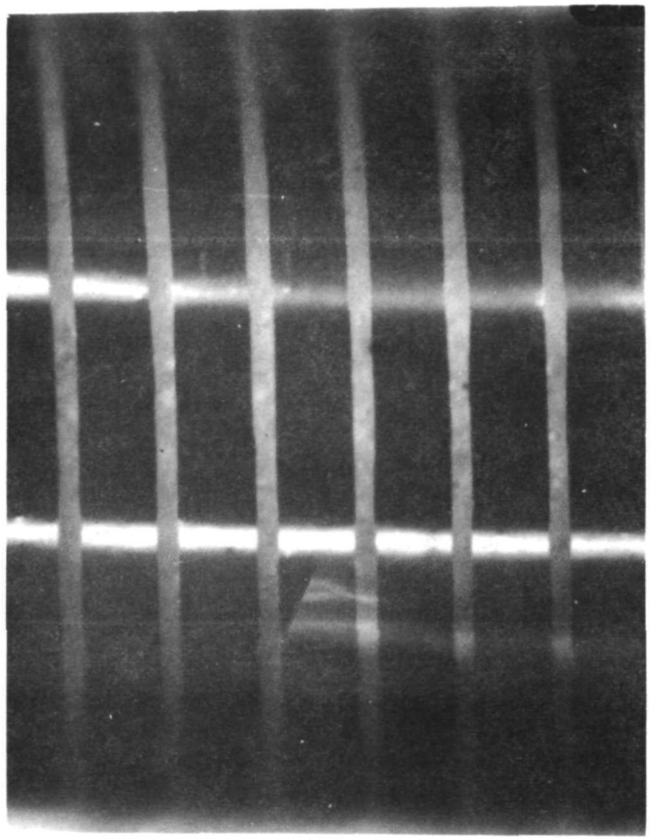


Figure 2. Stability of Nichrome in Good Resistor

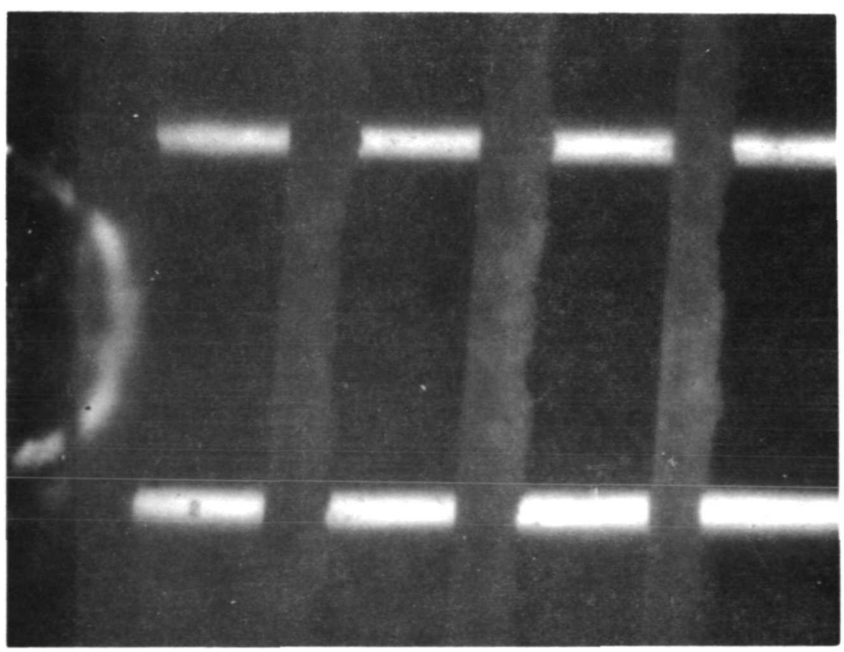


Figure 3. Removal of Nichrome in Bad Resistor

resistance values or drift. This premise formed the basis for the detailed drift mechanism study outlined in the following sections.

SECTION II. VENDOR MATERIALS AND PROCESSES

A. DESCRIPTION OF ITEM

The actual resistance element is a film of nichrome V on the interior of a ceramic tube (figure 1). The final resistance of the vapor-deposited nichrome is adjusted to the derived nominal resistor rating by spiral cutting to remove part of the metal and, thereby, restricting the effective cross-sectional area and increasing the effective length of conductor.

B. MANUFACTURING PROCESS

These resistors are made by the Vamistor Division of Wagner Electric Company, Cedar Knolls, New Jersey. This firm makes both hermetically sealed and non-sealed resistors. The flow sheet (figure 4), covers the essential features of Vamistor's hermetically sealed resistor production line. The following paragraphs comprise a brief sequential description of the manufacturing operations indicated on the flow sheet. The key starting materials are described later.

Steatite L-5 tubing in two different length-diameter combinations is used to produce the range of resistor sizes offered by Vamistor. At least three different vendors have supplied tubing to Vamistor in the past. Steatite L-5 is widely used in electrical applications of this type.

An internal glaze is applied to this tubing by forcing a water suspension of the glaze constituents through the tubing. The tubes containing the wet glaze are dried overnight in a vertical orientation and fired under progressively increasing temperature conditions that reach a specified maximum. Flow of the green glaze during overnight drying and subsequent firing causes a variable glaze thickness over the tube length. The glaze composition was developed some years ago, specifically for applications of this type. Two frit constituents of this glaze were withdrawn from the market in the interim by the supplier; however, Vamistor still obtains special orders of these frits from the same source by paying premium prices.

Both ends of the trimmed blanks are then dipped into toluene-thinned silver paste and fired. This creates a conductive bridge for electrically joining the silver plated endcap and the nichrome metallized layer.

Metallizing is done in a conventional Veeco vacuum metallizer. Thickness of the metallization treatment is determined by equipment settings which, during past experience, have yielded nichrome thickness

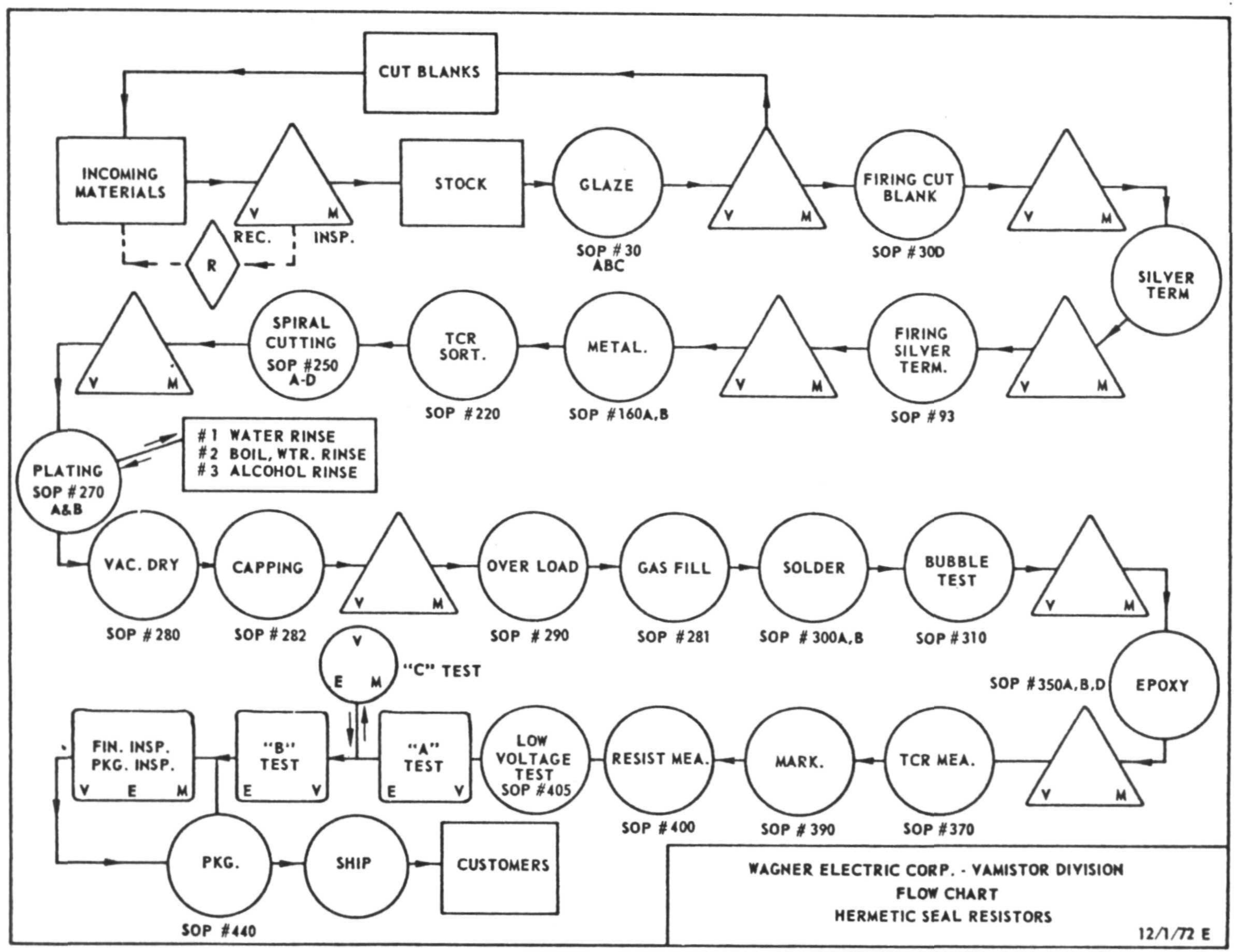


Figure 4. Flow Chart, Vamistor Division Hermetic Seal Resistors

consistent with the resistance values sought. Appropriate metallizer control settings are tabulated for each resistor type. The resistor type also determines which of two nichrome V wire gauges will be used.

The next step following the vacuum metallizing process is a 250 degrees C (482 degrees F) exposure in air to stabilize the resistance of the nichrome deposit. The attainment of a stable resistance value is verified by repetitive temperature coefficient of resistance (TCR) measurements.

The spiral cutting operation is next in sequence and is, basically, a final adjustment of the resistance. The metallized blank and a carbide burr are chucked in small, opposed, rotating jaws which are advanced by the cutting machine operator. The rotating carbide burr removes a strip of the metal deposit from the interior of the blank in a helical pattern (see figure 1). In-process monitoring of the resistance value enables the operator to gauge the proper depth of cut (or number of spirals) to attain the desired resistance value.

The blanks are copper plated, after ultrasonic cleaning, using a special machine to apply a copper brush plating solution to the outside of the silver termination at each end of the blank. Whether or not the copper plating solution contacts only the outside of the resistor elements is a question of obvious significance. Proper contact with the exterior of the resistor and minimal contact with the interior can be reasonably ensured only by a precise adjustment of the plating machine; and this setting would drift because of wear of the system elements.

Plated resistors drop out of the plating machine into a stagnant tap water bath that is changed for each specific lot or batch of resistors. Since the number of resistors in each batch can vary widely, there is considerable variation in the length of time and the severity of exposure diluting the plating solution in this tray.

After rinsing the plated items in running tap water, they are subjected to a sequence of rinsing and cleaning operations in distilled water and isopropanol. The flow sheet (figure 4), indicates the cleaning procedures in effect when the initial problems were experienced with these resistors. In an effort to resolve these problems a more elaborate cleaning method, also shown on the flow sheet, was adopted during October of 1972. Vamistor personnel maintain that these changes have improved the situation. The Vamistor staff principally credits the incorporation of a boiling distilled water exposure for the apparently improved effectiveness of their revised cleaning sequence. Vigorous boiling of distilled water in which small resistors are immersed is more effective than manual agitation or ultrasonics in removing internally trapped bubbles that would otherwise inhibit the rinsing operation. The rinse solutions were originally changed every 2 hours, regardless of the production rate.

The 2-1/2-hour vacuum drying operation at 100 degrees was inaugurated coincidental with the expanded cleaning operations. The permanent effectiveness of this drying step is subject to question because vacuum-dried items are stored in the shop environment for a variable time before endcapping. The silver plated endcaps, with leads attached, are force-fitted around the outer diameter at each end of the resistor. After a short-time overload test, the items are subjected to a "helium backfill." The endcapped resistors are placed in a vacuum chamber, and after the attainment of 20 to 30 millimeters of mercury (mm Hg), the system is pressurized with helium to 13,798.5 newtons/square meter [20 pounds per square inch gauge (psig)] and held for at least 15 minutes. This treatment is rendered worthless because the "backfilled" resistors are again stored, for a variable period at shop conditions, to await soldering. Any helium present in the interior of the resistors would be rapidly exhausted by leakage and diffusion into the atmosphere. Vamistor personnel candidly concede the undoubted futility of this operation, but it is carried out, nevertheless, in order to support some early advertising claims that were made for this product.

The soldering operation is done by machine and a standard 60/40 lead-tin solder is utilized in conjunction with a white rosin flux. This is followed by a MIL-R-55182 leakage test during which the resistors are submerged in a hot oil. A leak in any resistor is detected by a trail of rising bubbles. Epoxy overcoating is accomplished in two stages, each utilizing separate epoxy resins. The first resin is applied for a fluid bed and the parts are conveyed through a curing oven at 180 degrees C. A second epoxy resin, with purely a cosmetic function, is applied over the first coating. From this point, the items are subjected to final tests, packaging, and shipment.

C. MATERIALS AND ENVIRONMENTAL CONSIDERATIONS

Virtually all materials used by Vamistor are accepted standards in the electrical industry; however, the attributes and characteristics of these materials were reviewed for any possible individual or synergistic contribution to the observed drift in resistor characteristics.

The Steatite ceramic tube material is widely used in electrical component manufacture. Consultation with suppliers verified that this material is made to acceptable standards. Permeability to moisture is immeasurably low.

Samples of the glaze suspension were applied locally, by spray techniques, in order to conserve materials and to obtain more uniform coatings on the flat test substrates (to be described later). Isolated grains of apparently undissolved material could be detected in virtually every fired glaze sample. This effect can more likely be attributed to a propor-

tion of coarse material than to a true solubility limitation. Screening the glaze through 270 mesh largely eliminated this behavior. The slurried glaze was highly thixotropic, an attribute that complicates handling and processing and forced the use of thinner suspensions for the sprayed samples mentioned earlier. It was concluded that none of these factors indict the glaze material; however, a representative of the firm which supplies most of the glaze constituents implied that better glazing compositions for this type of application are now known. The present composition was developed back in 1955.

The conductive silver paste was examined in some detail. A chemical analysis of this product is shown in table 1. Like similar products, this

Table 1. Composition of Silver Paste

Ingredient	Per Cent by Weight
Silver	69.3
Leak	2.5
Silica	1.07
Titanium	0.14
Total Solids after Drying at 118°C	81.1
MEK Soluble Solids	8.6

NOTE: The MEK (methyl ethyl ketone) - soluble constituent was a complex resinous substance.

composition appears to contain an organic resin constituent which imparts film-forming properties at room temperature. Firing at elevated temperatures burns out the organic film former and presumably forms a final lead glass binder for the particulate silver. The proportions of lead and silica and the firing temperature are consistent with the lead glass binder formation. Several conductive silver pastes of this type are marketed. The widespread use of such products, in the manufacture of electrical goods, indicates that the paste is not at fault.

The nichrome wire used in the vacuum metallizing process was confirmed by analysis to be nichrome V. The surface active agent used in the post-spiral cutting ultrasonic cleaning solution is sodium dioctyl sulfosuccinate, a well known and highly effective product.

The copper plating operation required considerable attention because it is a major difference between the production processes used at Vamistor for unsealed and hermetically sealed versions of their resistors. The hermetically sealed resistors appear to be more vulnerable to resistance drift than the unsealed units, based upon tests conducted at MSFC. Because contamination or residues arising from the plating solution could be involved, the plating solution was studied in detail.

The manufacturer of the copper alkaline plating solution declined to reveal its composition, but acknowledged that more than one compound is present, including a basic organic material. The solution was found to contain 27.3 percent non-volatile residue which, in turn, had the composition shown in table 2.

Table 2. Chemical Analysis of Non-Volatile Residue from Alkaline Copper Plating Solution

	Experimental		Calculated
	Analysis, Weight	Gram Atoms	Analyses
	Percent	Per 100 g.	$Cu[C_2H_4(NH_2)_2]_2SO_4$
Nitrogen	19.0	1.36	20.0
Carbon	16.5	1.37	17.2
Hydrogen	4.7	4.66	5.8
Copper	23.1	0.36	22.7
Sulfate	34.4	0.36	34.3
	97.5		100.0

It is evident that the tabulated elements account, within experimental error, for the total composition. Copper and sulfate are present in equivalent proportions, as are nitrogen and carbon. The occasional addition of organic brighteners (and other additives) is not believed sufficient to account for the high percentage of carbon found in this product. Consequently, it is believed to be a transition metal complex wherein organic amines are coordinated to the available 3d orbitals of the copper ion as mono- or bidentate ligands. Two ethylene diamine molecules, therefore, could serve as bidentate ligands to provide a cupric bis (ethylenediamine) sulfate complex having the theoretical composition shown in table 2. This is quite close to the experimental values shown; thus, in the manufacturer's cryptic description, this amine could be the "basic organic material."

During the time under consideration, plated units emerging from the plating machine fell directly into a tray of stagnant tap water. Each batch of resistors was accumulated in that tray and subsequently exposed to the remaining rinse cycles. Every two hours - irrespective of the actual production rate - the "second rinse" vessels are placed in the "first rinse" positions and containers (filled with fresh solvent) are put in "second rinse" containers. The distilled water was checked conductimetrically at irregular intervals but no sustained in-process control of the rinsing media was maintained.

Table 3 shows the effect of varying production throughput upon the copper and sulfate content of water in the catch pan at this end of the plating machine. It is obvious that the inner surfaces of resistors made during a

Table 3. Effect of Production Variations on Catch Basin Contamination

	Resistance (Ohms)	Copper (PPM)	Sulfate (PPM)
Sample from Catch Basin After 300 Piece Run	1.4×10^3	200	344
Sample from Catch Basin After 20 Piece Run	3.4×10^3	18.1	47
Sample from First Distilled Water Rinse	3.9×10^4	0.27	4
Sample from Final Isoppropyl Alcohol Rinse	-----	0.05	4

large order would be exposed for longer periods to higher concentrations of plating bath contaminants. However, analyses of the first distilled water rinse and the final alcohol rinse of the new cleaning procedure indicate that these levels of contamination are later reduced to low values in the rinse liquids.

None of the materials used during the remainder of the process can be faulted in any obvious way; however, there are processing anomalies. The effectiveness of the vacuum drying operation that follows the rinsing cycle is, at least, partially nullified by the re-exposure of the components to stop environment prior to endcapping. The endcapping operation is accomplished in the same environment (45 to 65 percent relative humidity); therefore, if.any hygroscopic residue remained from the plating operation, it is highly probable that a quantity of electrolyte solution would be sealed within a given resistor. This was demonstrated to be the case by chemical analyses described in section III.

SECTION III. CHEMICAL EXAMINATION OF RESISTORS

A. MICROSCOPIC ANALYSIS OF RESISTORS

Detailed comparative examinations of good (non-drifting) and bad (drifting) resistors were carried out using optical and scanning electron microscopy. The first samples of drifting resistors were analyzed by stripping away the epoxy coating, filing off one endcap carefully, and filling the interior of the resistor with a water-white epoxy. The epoxy was allowed to set up and the resistor was sectioned longitudinally and polished. The epoxy preserved the condition of the nichrome and precluded any damage due to sectioning; thus, it was established that the degree of nichrome damage observed in subsequently examined resistors, was solely a function of the electrochemical process.

The nichrome disappearance in the bad resistors followed several patterns. In most of the resistors examined, the turns of nichrome at each end of the helix were only slightly affected and the gross nichrome removal occurred at several of the inner turns. The resistor shown in figure 5 is typical of this effect. This is an RNR55C 1/10-watt, 19,100 ohm resistor which was removed from an ATM flight PC board (P/N 50M12745-9) after drifting 9.2 percent in resistance value. Only the two center cuts are involved in the nichrome removal. Even in the case where the resistor goes electrically open (figure 6) the end turns are not significantly involved. This is an RNR55C, 1/10-watt, 49,900 ohm resistor, date code 7234, which opened in the QUAL Laboratory test matrix after approximately 800 hours at room temperature and 25 percent VR.

The complete removal of nichrome across one band, between cuts three and four from the right (figure 6), resulted in an electrical open in the resistor.

The directional effect of the nichrome removal, as a result of dc voltage testing, is a second pattern that is quite consistent. Figure 7 illustrates this effect clearly. The light areas represent nichrome removal. In tests where the polarity of the voltage was observed, the nichrome was removed on the side of the cut corresponding to the lower negative potential (see figure 6). This would correspond to the anode in an electrolytic cell. The positively charged nickel and chromium ions would then migrate in the direction of higher negative potential, whether this is the next turn of nichrome or the end of the resistor body.

The nichrome surface is hydrophobic relative to the ceramic cuts and it is very probable that localized concentrations of plating solution residue are preferentially located in these cuts. Accordingly, if the tool

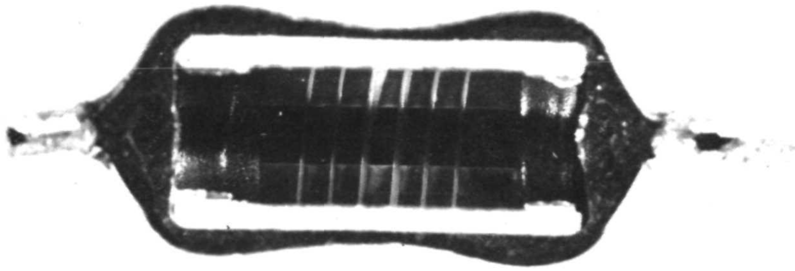


Photo 1. 10X

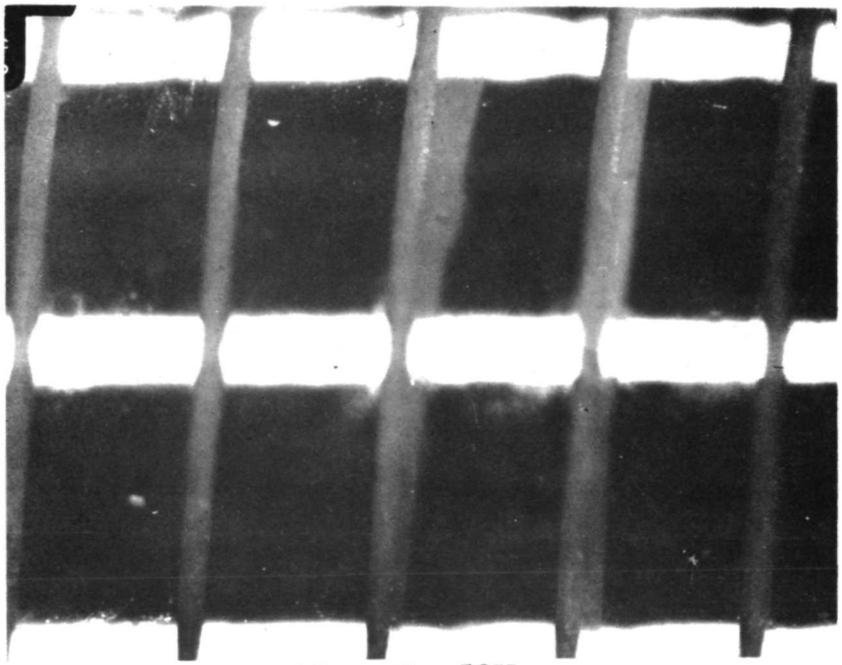


Photo 2. 52X

NOTE: The horizontal white bands are light reflections from the curved surface and should be ignored.

Figure 5. Drifting RNR 55C Vamistor Resistor

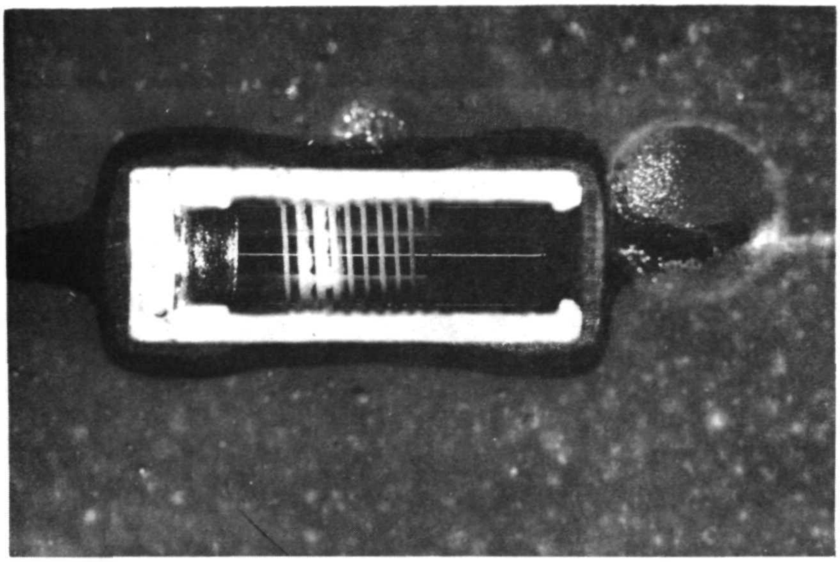


Photo 1. 10X

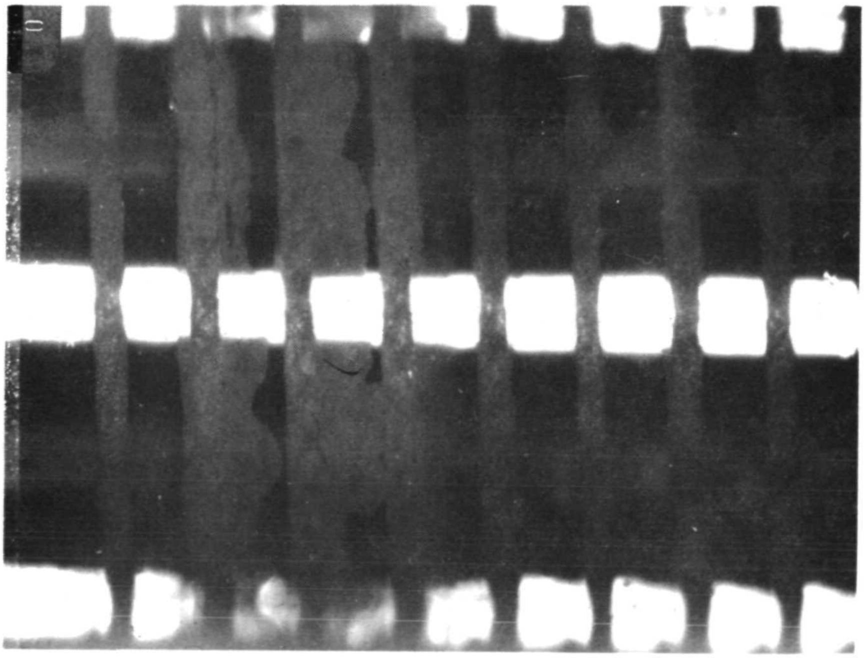


Photo 2. 52X

NOTE: The horizontal white bands are light reflections from the curved surface and should be ignored.

Figure 6. Open RNR 55C Vamistor Resistor

Figure 7. Illustration of Directional Effect in Nichrome Dissolution after DC Voltage Stress

which makes the helical cut is disrupting the nichrome glass/bond, the plating solution may penetrate to this extent and aggravate the nichrome dissolution process. It was shown, however, that this was an unlikely event by the use of SEM photomicrographs of the edge of the cut where the nichrome glass interface begins. Figure 8 illustrates the angle of observation of the cut and figure 9 show the smooth edge of the cut, from two different resistors (even at 10,000 X magnification), indicating no irregularities that might be consistent with damage to the nichrome/glass bond.

At least two additional anomolous conditions were observed in drifting resistors as shown in figures 10 and 11. In figure 10, microprobe analysis indicated that the green crystalline deposit was a copper compound, but the sulfate anion was not detectable. In figure 11 microprobe analysis indicated an iron compound. The established pattern of nichrome removal was apparently not affected by these contaminants and it appears unrelated to the electrochemical phenomena; however, the presence of the extraneous materials in figure 10, 11, and 12 expand the concern over the vendor's inadequate contamination control requirements at the time of manufacture.

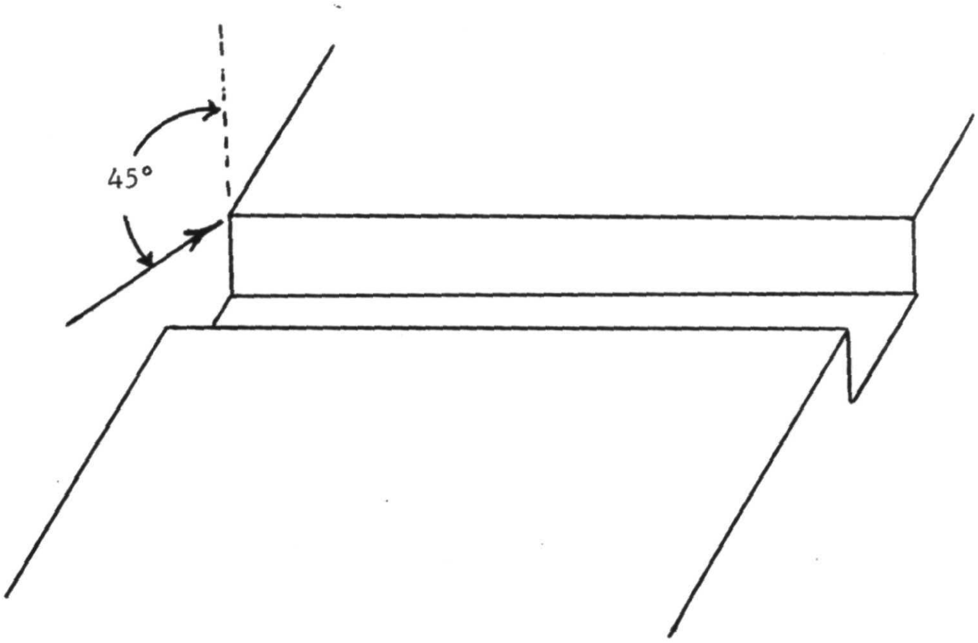


Figure 8. SEM Inspection of Nichrome Cut

B. CHEMICAL ANALYSES OF INTERNAL CONTAMINATION

The high probability of residual contamination from the copper plating operation prompted a series of chemical analyses primarily directed toward detection of copper and sulfate ionic species in the resistors. In a typical case, 10 electrically good resistors and 10 drifting resistors were crushed in separate beakers of deionized water (10 megohm resistance) and the two solutions were stirred with heating for one hour. Copper was determined by atomic absorption and sulfate was precipitated with barium chloride under acid conditions. Copper concentrations of 0.1 to 0.8 parts-per-million (ppm) and sulfate concentrations of 20 to 40 ppm were observed with no consistent pattern of higher concentrations of contaminants in drifting resistors.

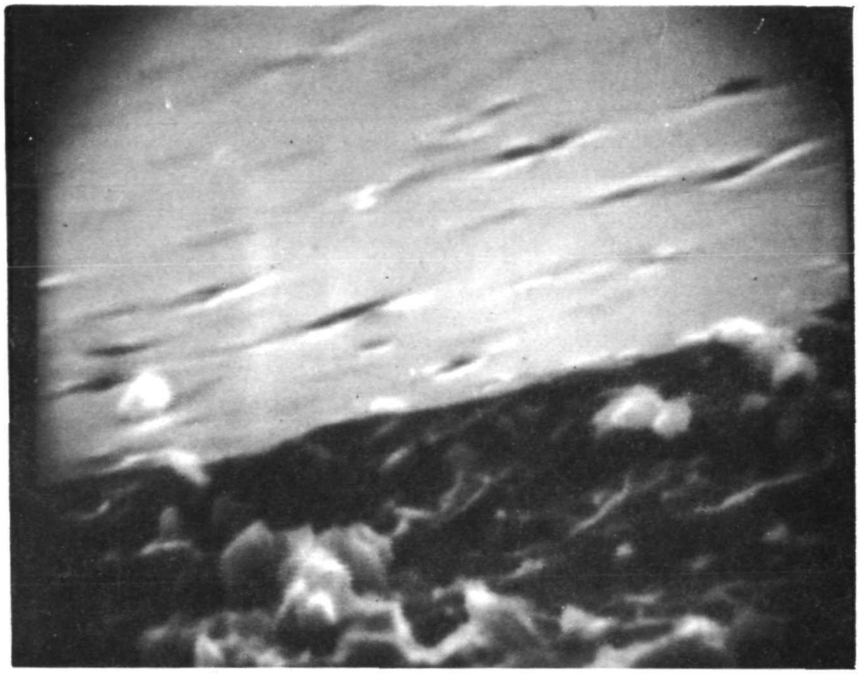


Photo 1. 10,000 X

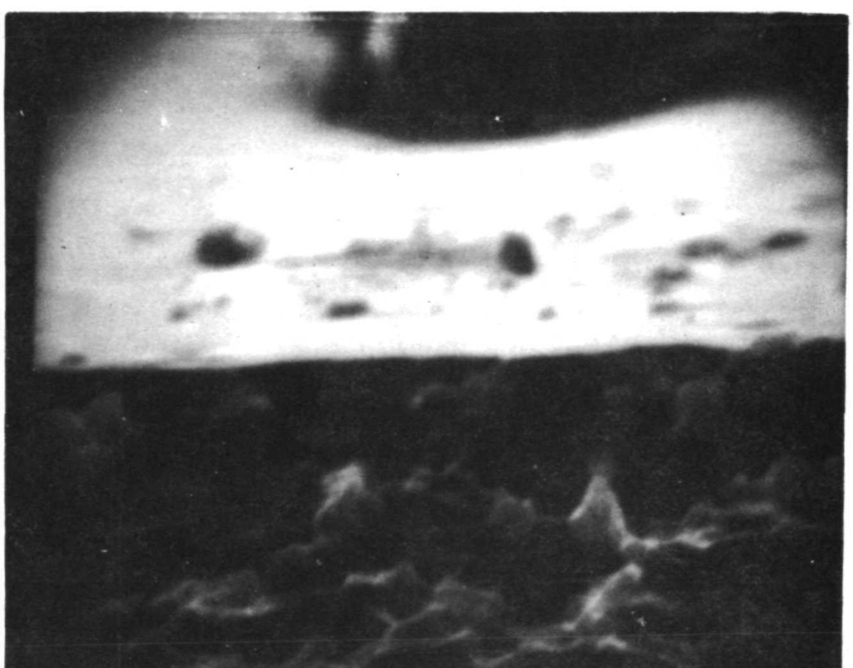


Photo 2. 10,000X

Figure 9. SEM Photomicrograph of Nicrome Cut

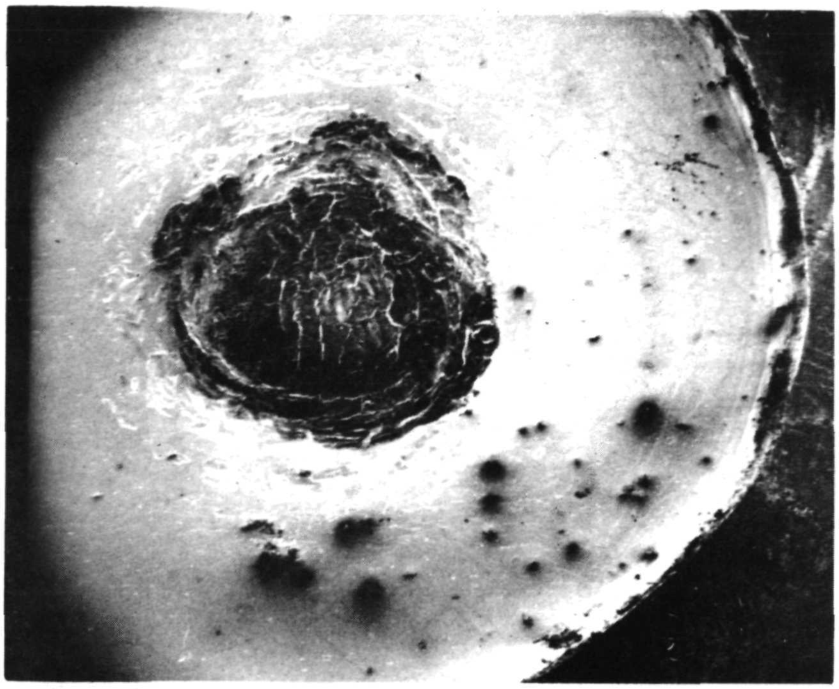


Figure 10. Copper Salt Contamination on Resistor Endcap

Figure 11. Iron Deposit on Nichrome Band in Resistor

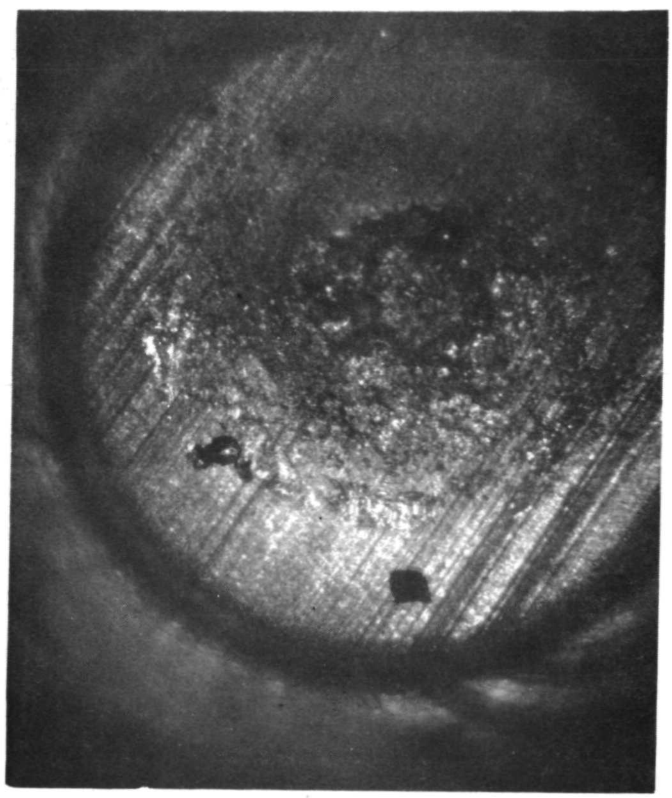


Figure 12. Copper Deposit on Resistor Endcap

Considering the nature of the plating process, a reasonable assumption is that certain levels of electrolyte contamination are present in all of the hermetically sealed resistors, and negative tests for the various ionic species inside the resistors tend to reflect contamination levels below the limit of sensitivity of the particular analytical technique utilized.

A further series of analyses were performed to determine the composition of the atmosphere within the resistor. For this analysis, the epoxy coating on the resistors was removed and the resistors were placed in a copper tube leading to the gas inlet of a mass spectrometer. The tube and inlet were pumped down to low pressures, with heating to remove residual water from the system. The resistors were then crushed and the internal atmosphere was bled into the mass spectrometer. The following constituents were found: Oxygen, Nitrogen, Hydrogen (trace), and Water. No Helium was detected. The water detection was approaching the lower limit of sensitivity of the equipment and no definite correlation could be established between bad resistors and high moisture content; however, moisture is definitely present in the resistors and it must be considered that the quantity is sufficient to provide the medium for operation of an electrochemical process. The absence of helium in detectable quantities further demonstrated the inadequacy of the inerting step in the manufacture of the resistor.

SECTION IV. NICHROME ELECTROLYTIC CELL STUDIES

As an adjunct to understanding the nature of the electrochemical process operating inside the resistors, a series of nichrome electrolytic cell studies was carried out. The cell for this study is shown in figure 13.

It should be noted that the observations made in this section cannot be applied to quantitatively predict resistor drift; however, the basic electrochemical processes can be studied using this mode to provide qualitative or relative data.

Initially, tests were conducted to determine time, voltage, and plating solution concentrations necessary to effect anodic dissolution observed in the actual resistors. Voltages from 0.9 to 5.0 vdc were utilized, with a concentration of plating solution of 5.0 percent by volume, based on the original concentration of solution supplied by Vamistor personnel. The exposed area of the nichrome electrodes was 5.1 cm^2, with a spacing of 2.54 cm. Figures 14 and 15 are shown for comparison of the electrolytic effects on anode and cathode through this voltage range. In figure 14 there is a very minor effect on the anode after 64 hours at 0.9 vdc. The effect is progressive with increasing voltage and is reasonably linear with time up to approximately 1.5 vdc. At higher voltages the anode dissolution is much

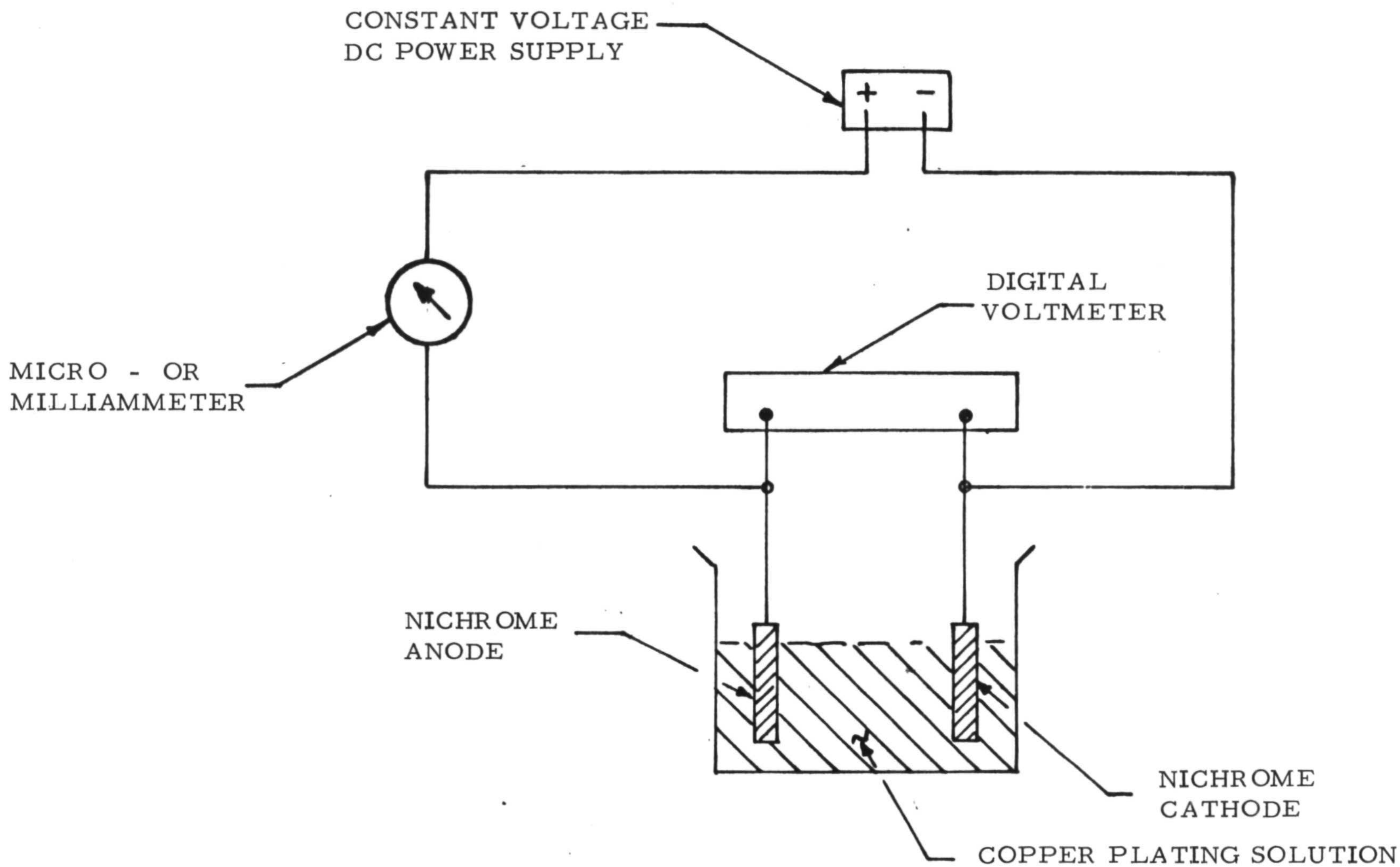
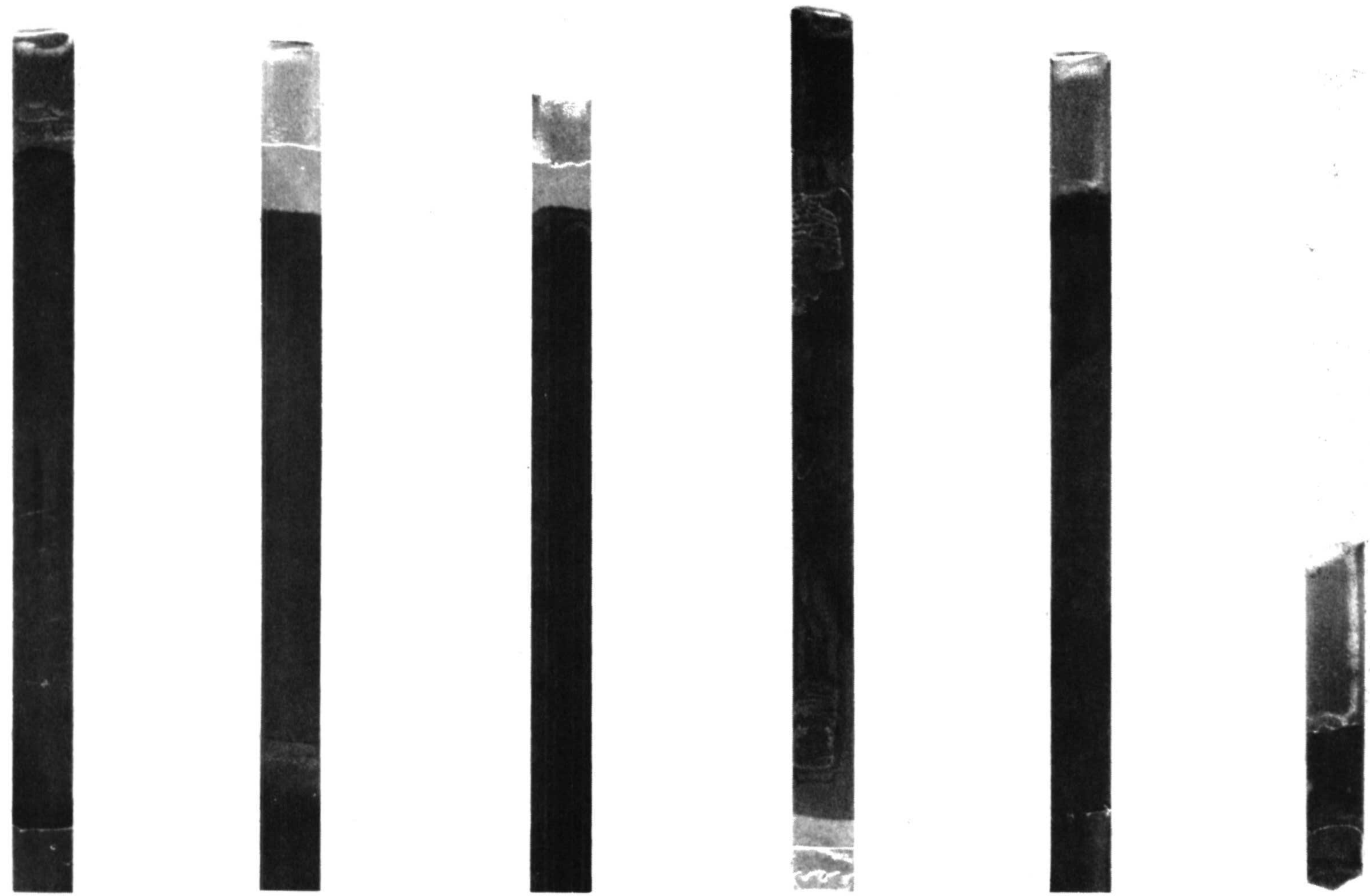


Figure 13. Experimental Nichrome Electrolytic Cell



0.9V (64 HRS) | 1.0V (64 HRS) | 1.1V (64 HRS) | 1.25V (64 HRS) | 1.5V (19 HRS) | 5.0V (2 HRS)

Figure 14. Anode Dissolution As A Function Of Cell Voltage

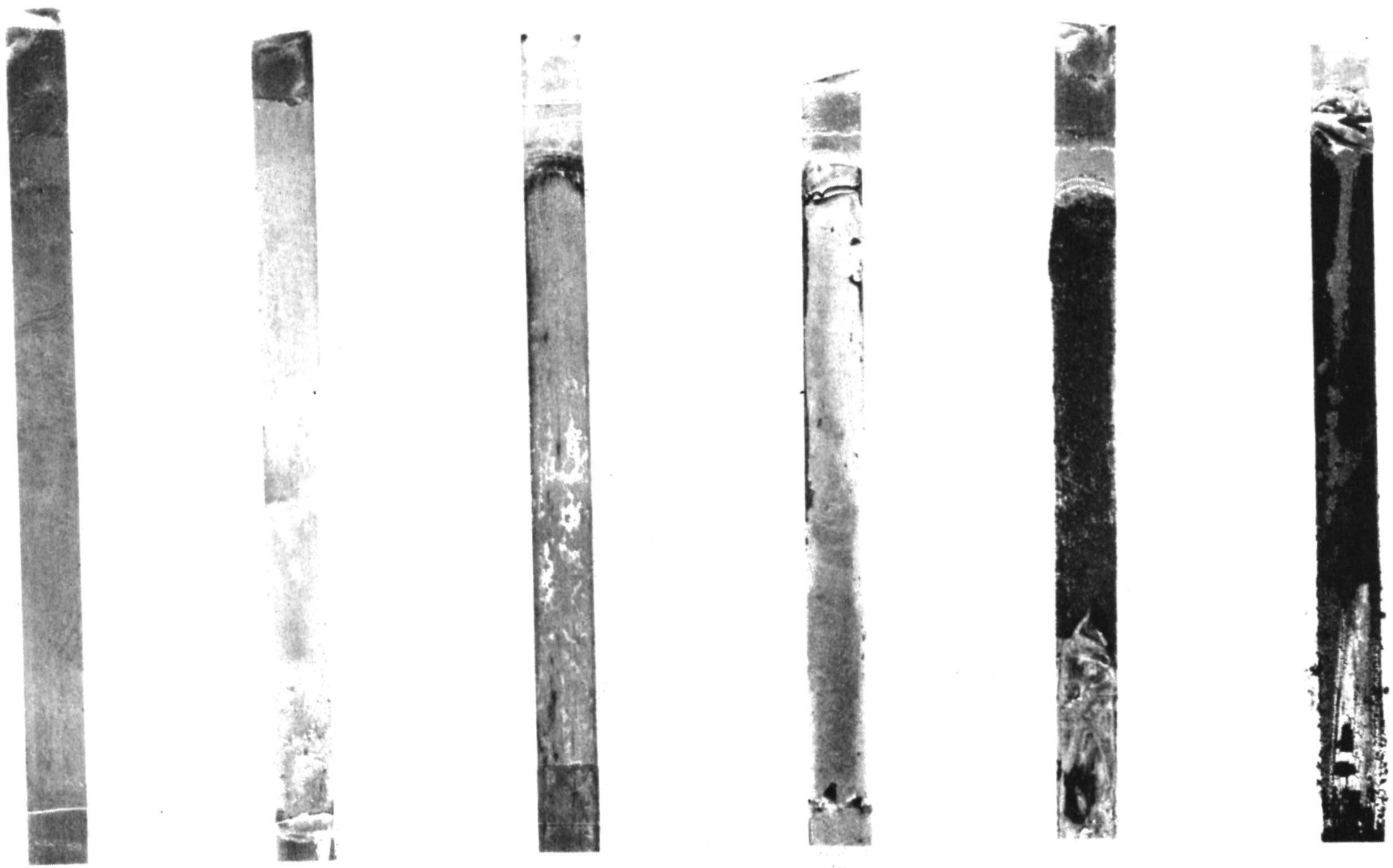


Figure 15. Cathode Deposition As A Function Of Cell Voltage

more rapid and at 5 vdc the cell circuit is opened from complete dissolution of the anode in two hours. Figure 15 shows the corresponding cathodes with a progressive plating of copper from solution. There is no observable copper deposit on the cathode at the 0.9 or 1.0 vdc levels; although there is evidence of anode dissolution at these voltages.

The current was monitored during these experiments and the data were converted to resistance and plotted as a function of time in figures 16 through 21.

The resistance versus time graphs in figures 16 through 21 are consistently characterized by the initial decrease in resistance or increase in current. This is believed to be due to an increase in conductivity when the anode dissolution process releases Cr^{+3} and Ni^{+2} ions into solution; however, the concentration of metal ions in the electrolyte solution can only increase to the point of maximum solubility under those conditions. Beyond this point the metal ions are precipitated from solution as oxides or hydroxides and the ionic strength or conductivity of the solution becomes essentially constant. During this time the anode is decreasing in area; thus, tending to increase the resistance of the cell. Up to the point of maximum concentration of the solution, there has been a net decrease in resistance. Now the concentration of the cell is constant and can no longer offset the effect of loss of anode surface area. The result is an increase in resistance as reflected by the graphs.

The sequence of events attending a typical electrolytic cell experiment is as follows:

Initially, cathodic liberation of H_2 is observed, concomitant with the onset of anodic dissolution. This corresponds to the expected reduction-oxidation processes which constitute electrolysis:

Anode reaction: $Cr^o \longrightarrow Cr^{+3} + 3e^-$

$Ni^o \longrightarrow Ni^{+2} + 2e^-$

Cathode reaction: $2H^+ + 2e^- \rightarrow H_2$

The current in the circuit builds up during the initial phase of voltage application, reaches a maximum, and then begins to decrease with time.

The onset of copper reduction at the anode follows the H_2 liberation and becomes a concurrent process:

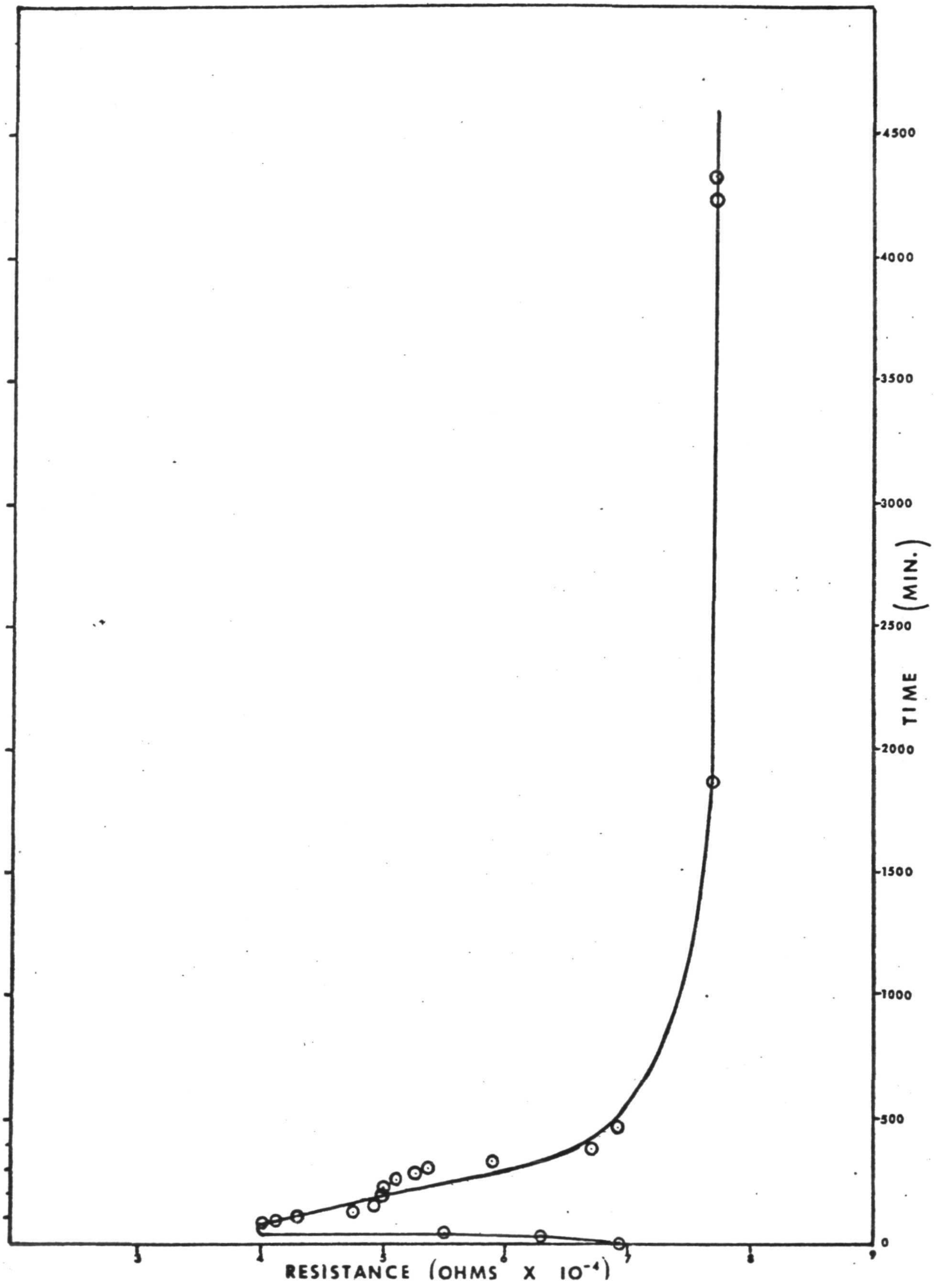


Figure 16. Resistance versus Time At 0.9 vdc

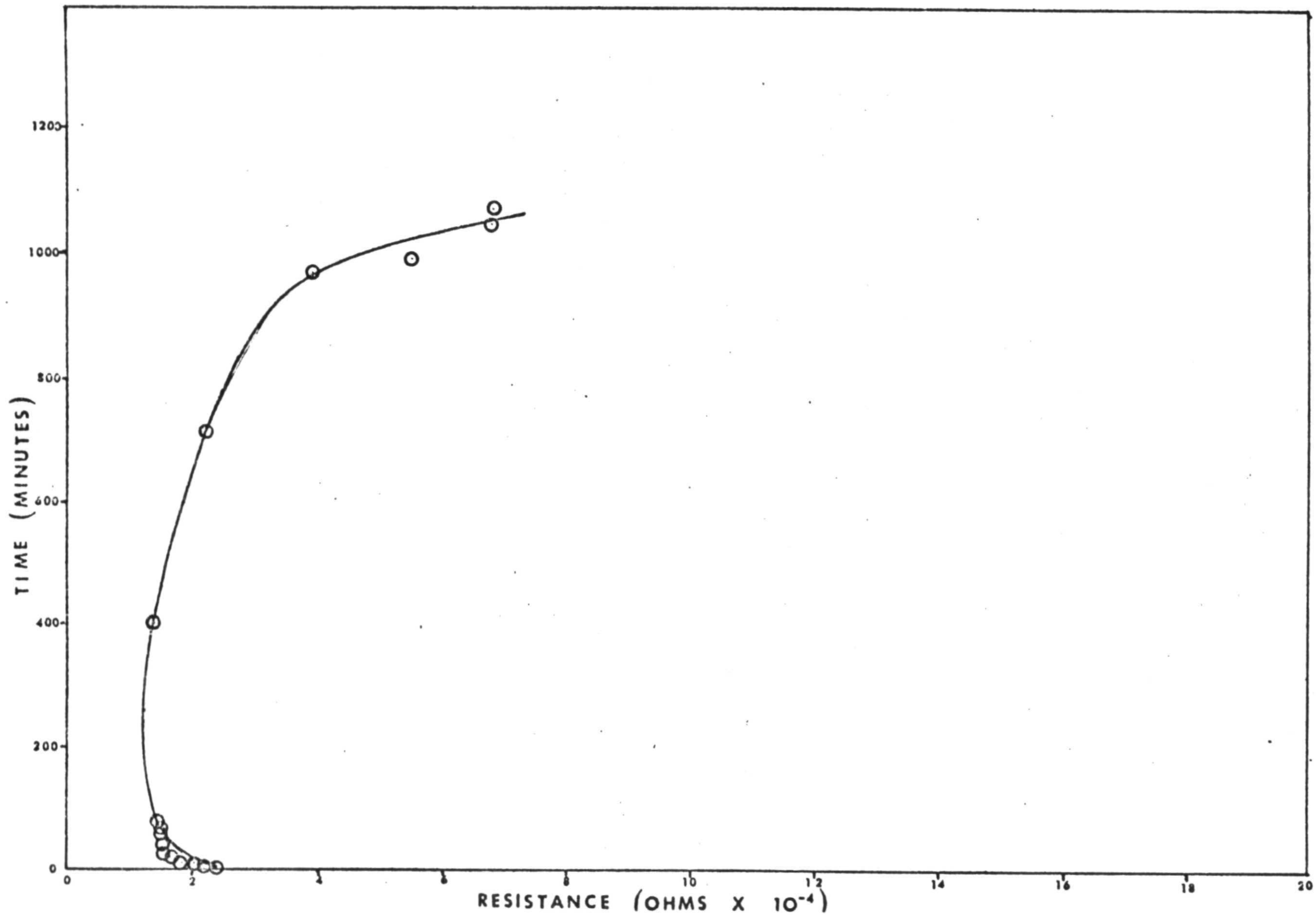


Figure 17. Resistance Versus Time At 1.0 vdc

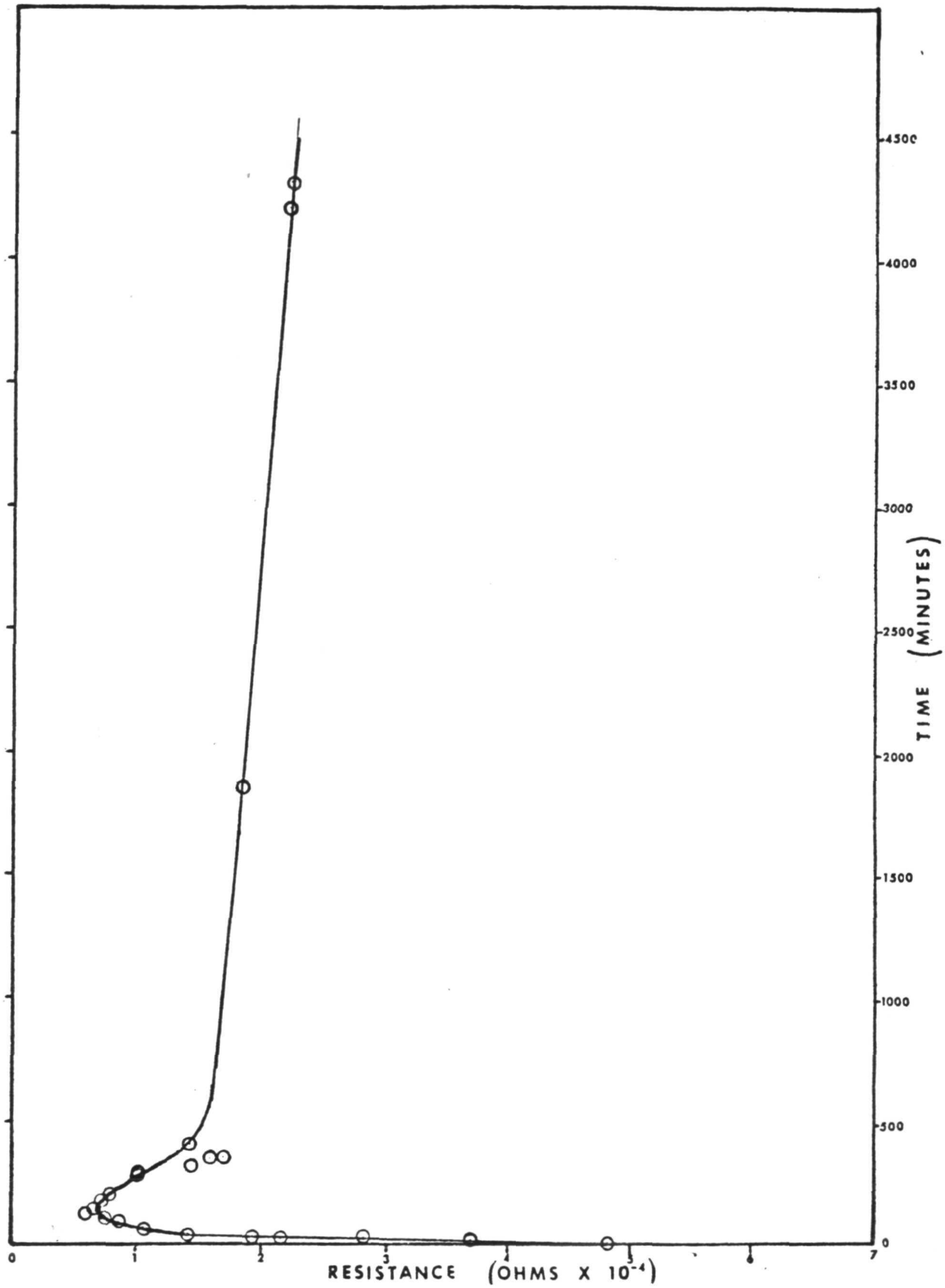


Figure 18. Resistance Versus Time At 1.1 vdc

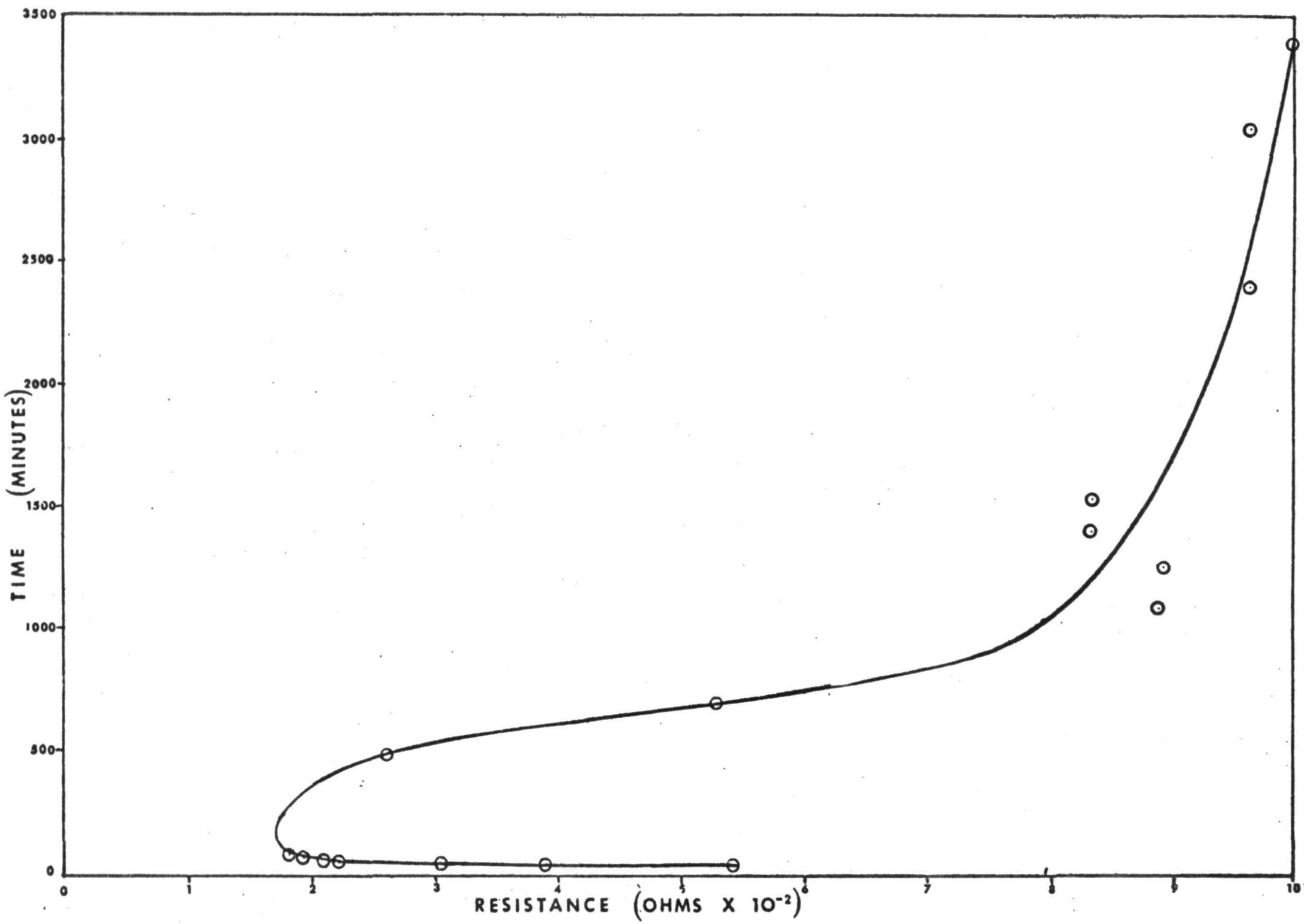


Figure 19. Resistance Versus Time At 1.25 dc

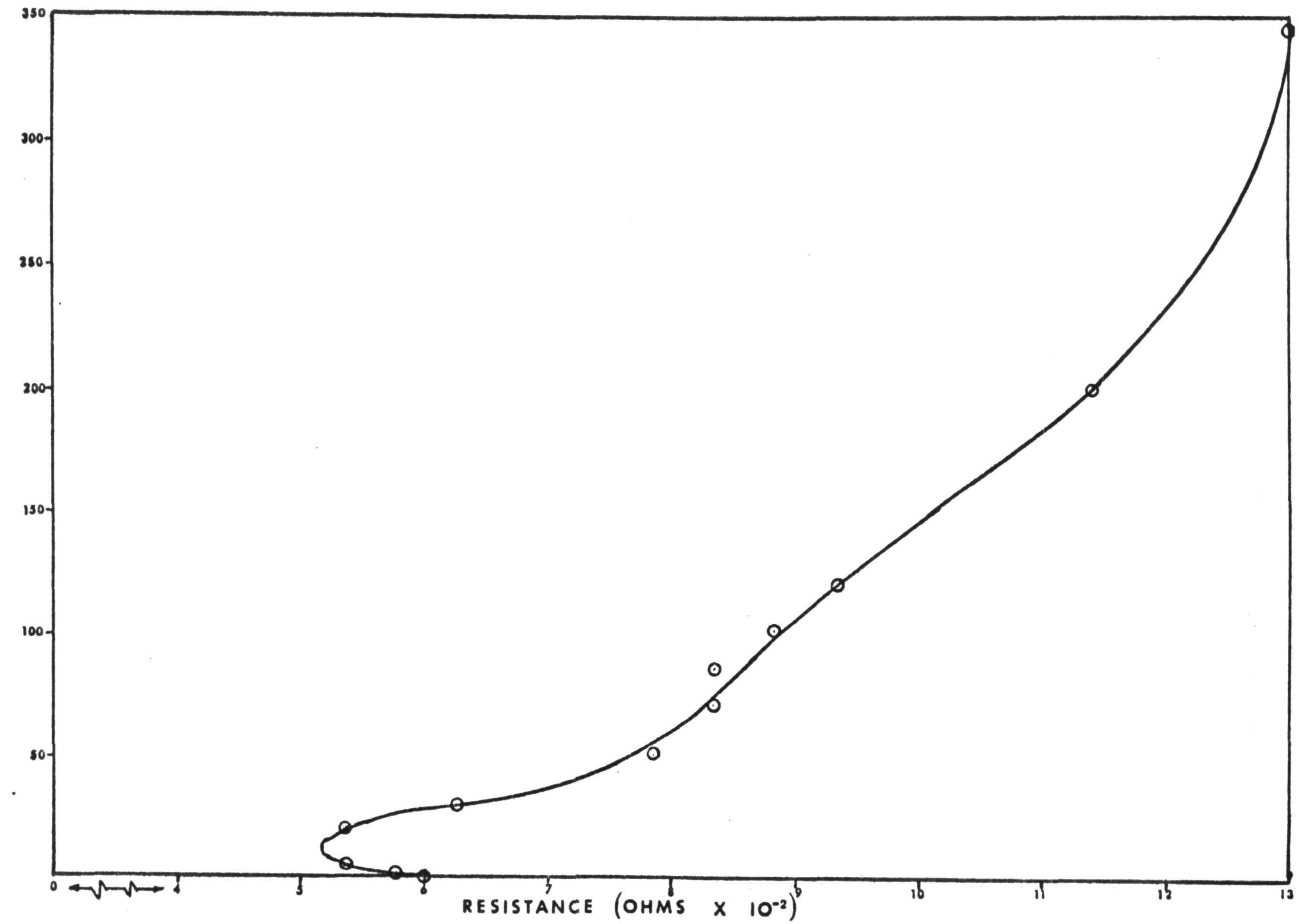


Figure 20. Resistance Versus Time At 1.5 vdc

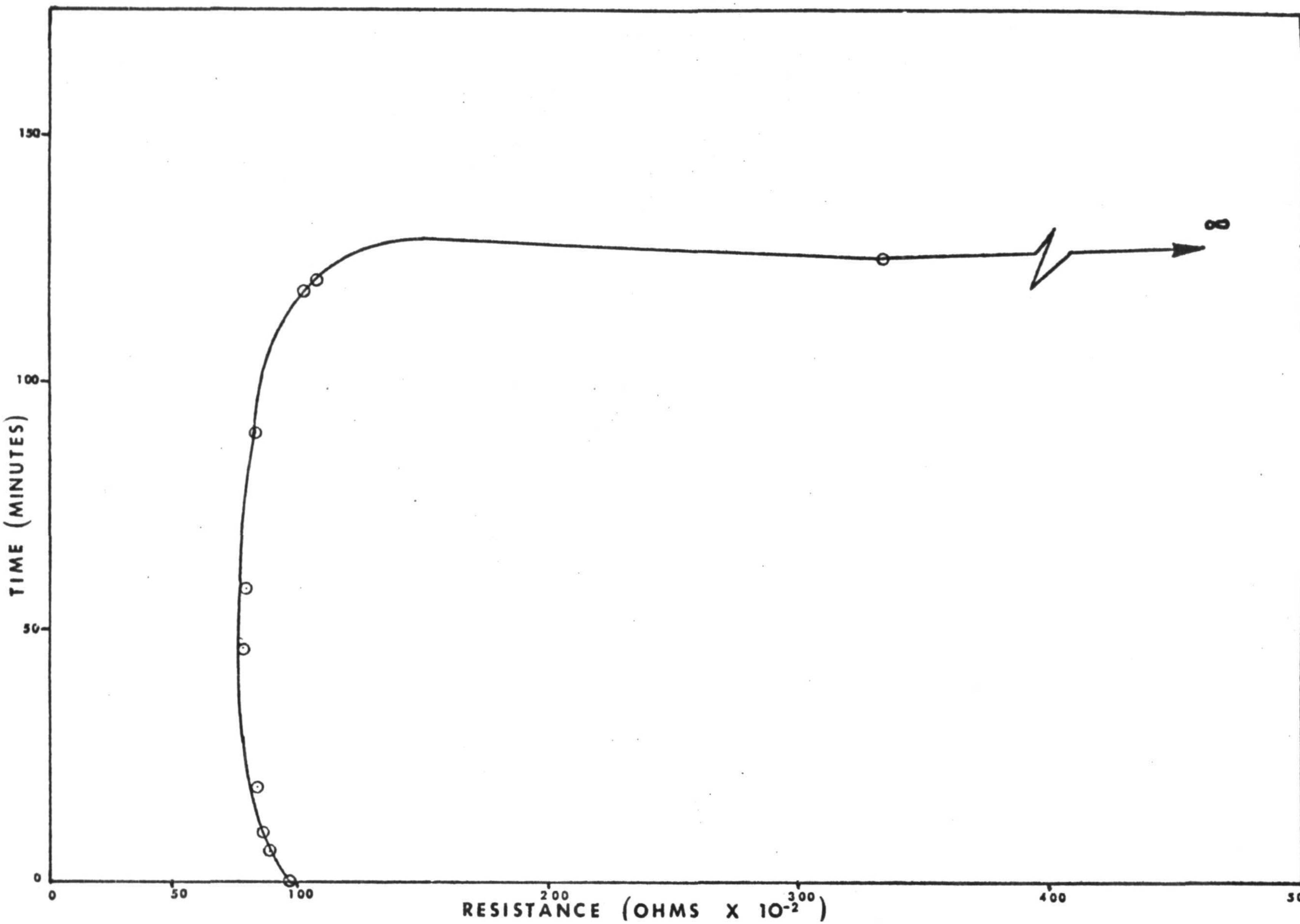


Figure 21. Resistance Versus Time At 5.0 vdc

$$Cu^{+2} + 2e^- \longrightarrow Cu^o$$

Alternatively:

$$Cu^{+2} + 1e^- \longrightarrow Cu^{+1}$$

$$Cu^{+1} + 1e^- \longrightarrow Cu^o$$

For higher voltage processes, where electrolysis of water is efficient, the chemistry of the cell becomes more complex; 0_2 is generated at the anode and converts chromium ion to higher oxidation states:

$$40H^- - 4e^- \longrightarrow 0_2 + 2H_2$$

$$Cr^{+3} + 40H^- \longrightarrow Cr0_2^- + 2H_20 + 3e^-$$

$$2Cr^{+3} + 7H_20 \longrightarrow Cr_20_7^{-2} + 14H^+ + 6e^-$$

As the process proceeds, a distinct yellow layer is observed below the unstirred purple plating solution. This corresponds to the anode dissolution and solvation of CR^{+3} and/or Ni^{+2} ions. Considerable amounts of yellow to brown precipitate collect in the cell, representing oxidation products of nickel and chromium, principally in the form of insoluble oxides and hydroxides. During this time, significant quantities of copper have plated on the cathode. The initially purple color of the plating solution is gradually replaced by the yellow Cr^{+3} color. It is believed that this is due to an equilibrium concentration of chromic acid which would shift the modestly basic pH of the solution to the acid side. The color of the plating solution responds readily to successive acid and base treatment, showing the color changes and regeneration to be that which is normally consistent with an acid-base dye or indicator. Thus, the primary contribution to the color of the solution is from a dye rather than the copper sulfate complex and the color changes in the solution during electrolysis cannot be followed as unambiguous evidence of copper depletion. As the electrolytic process continues the resistance increases because of reductions in the cross-section area of the anode. At higher voltage potentials, the anode is consumed within the experiment time frame and the cell circuit electrically opens as the remainder of the anode breaks contact with the surface of the solution. This would simulate complete dissolution across a point in one of the nichrome bands in the resistor, causing the resistance to increase to an open circuit. It is believed that many of these electrochemical processes take place in the resistor and constitute the basic mechanism for drift and, in the worst case, an electrically open circuit.

The onset of significant electrolytic activity in the area of 1.5 volts, as shown by the condition of the electrodes (figure 14 and 15), is considered quite significant and a series of current/voltage experiments were carried out to study the observation. Current versus voltage data were collected

using tap water, as well as plating solution concentrations of 2.5, 5.0, and 10 percent. The graphs in figures 22 through 25 illustrate this phenomenon and the extrapolation of the linear portion of the curve to zero current yields a voltage commonly termed the "decomposition potential" of the electrolyte. This value is largely independent of electrolyte concentration, as a four-fold variation in concentration results in a range of only 1.63 to 1.7 volts for decomposition potential. It is evident from these graphs that, as the voltage decreases through this region, the current decays exponentially. Since the current density available to an electrolytic process is the driving force for that process, in terms of anode dissolution and ion migration, one may envision a type of voltage threshold below which the electrolytic process cannot proceed efficiently. This phenomenon is believed largely responsible for the insensitivity to drift of the resistors at low voltage stresses.

The decomposition voltage is believed, also, to be largely independent of electrode separation, as an eight-fold change in electrode separation results in a variation in decomposition potential of only 1.54 to 1.66 volts.

The presence of a decomposition potential in electrolysis is predicated upon a reversible electromotive-force (emf) in the cell. In the nichrome electrode cell, anode and cathode are the same and an initial reversible or back emf exists. This was supported by electrometer measurements on resistors; however, the initial surge of current applied when the cell becomes operational will generate small amounts of hydrogen at the cathode and oxygen at the anode. These gases adhere to the electrode surfaces and simulate an O_2/H_2 gas electrode pair with a reversible emf which opposes the applied potential. As the voltage is increased from 1.7 to 1.8 volts (which) is the voltage range corresponding to continuous electrolysis of water) enough H_2 and O_2 are generated to exceed the confining atmospheric pressure and escape from the electrodes. With the voltage such that these gases can be evolved continuously, the electrolytic process proceeds efficiently. Also, as soon as some copper from the plating solution is deposited on the cathode, this initially inert electrode is transformed into an active copper electrode which allows generation of a reversible emf.

The foregoing cell studies reflect the electrochemical nature of the processes in the resistors. Tests were also performed to determine the relative effects of electrolyte concentration and voltage on the level of electrochemical activity over extended time periods. Tests were run at plating solution concentrations of 5, 2.5, 1.0, and 0.5 percent and with tapwater. Figure 26 displays dependence of resistance on time for the four electrolyte concentrations. A further extension of this data was obtained in figure 27, which relates the effect of concentration level on the time-to-failure or time-to-open of the cell. The failure time is somewhat insensitive to concentration down to a level of one percent, below which the effect of concentration is quite pronounced.

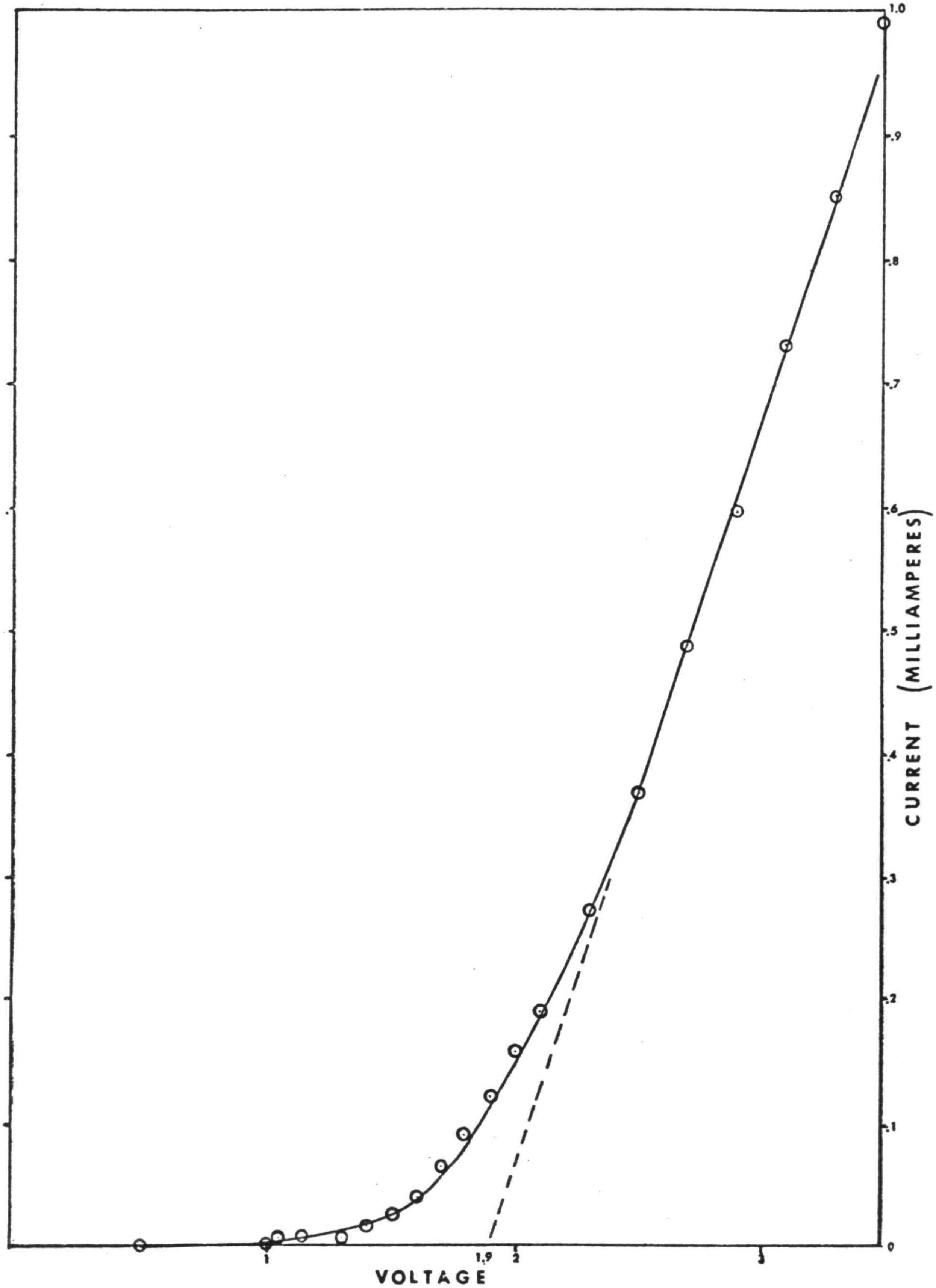


Figure 22. Current Versus Voltage At 1-Inch Electrode Separation-Tap Water.

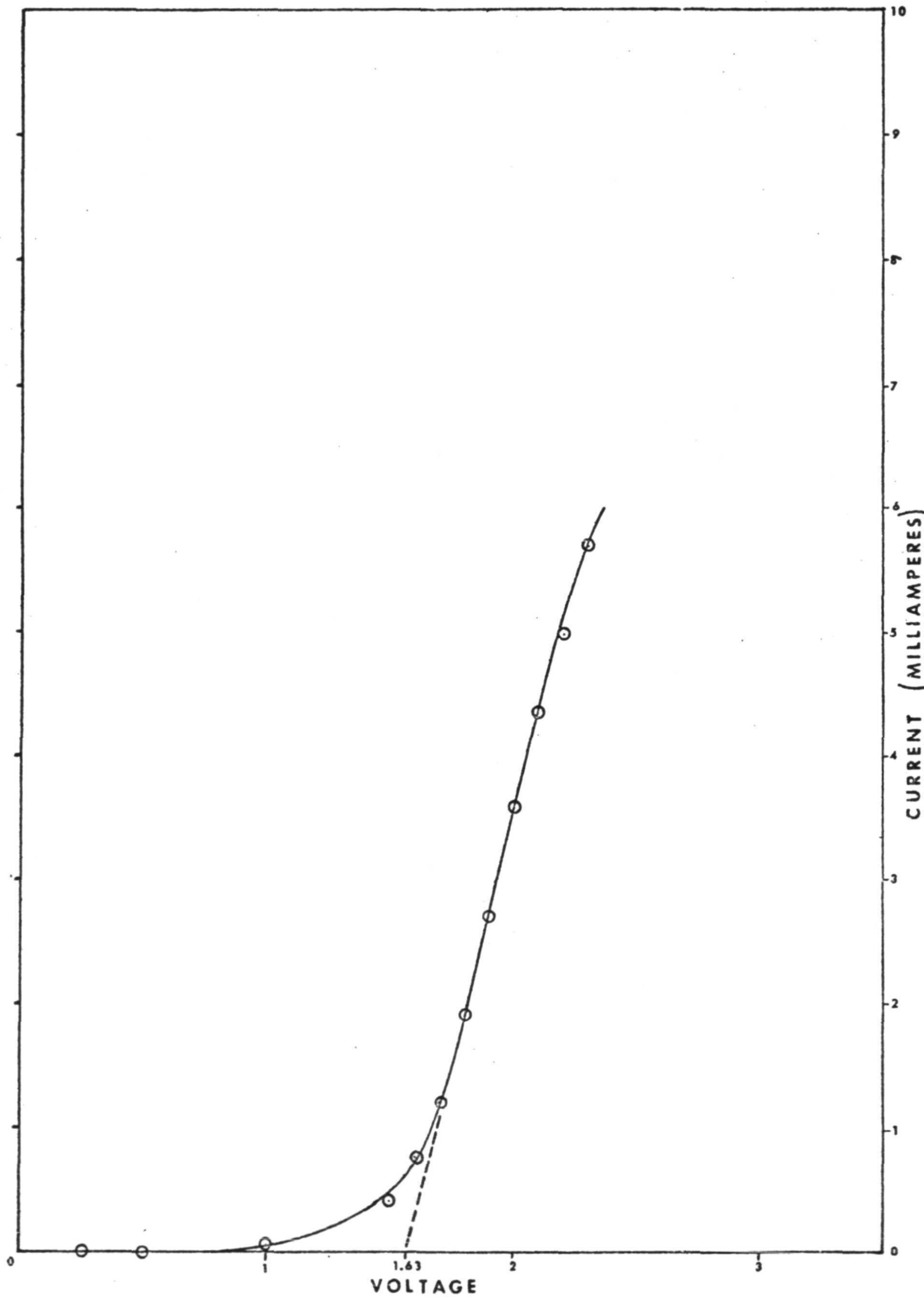


Figure 23. Current Versus Voltage A 1-Inch Electrode Separation-2.5% Plating Solution.

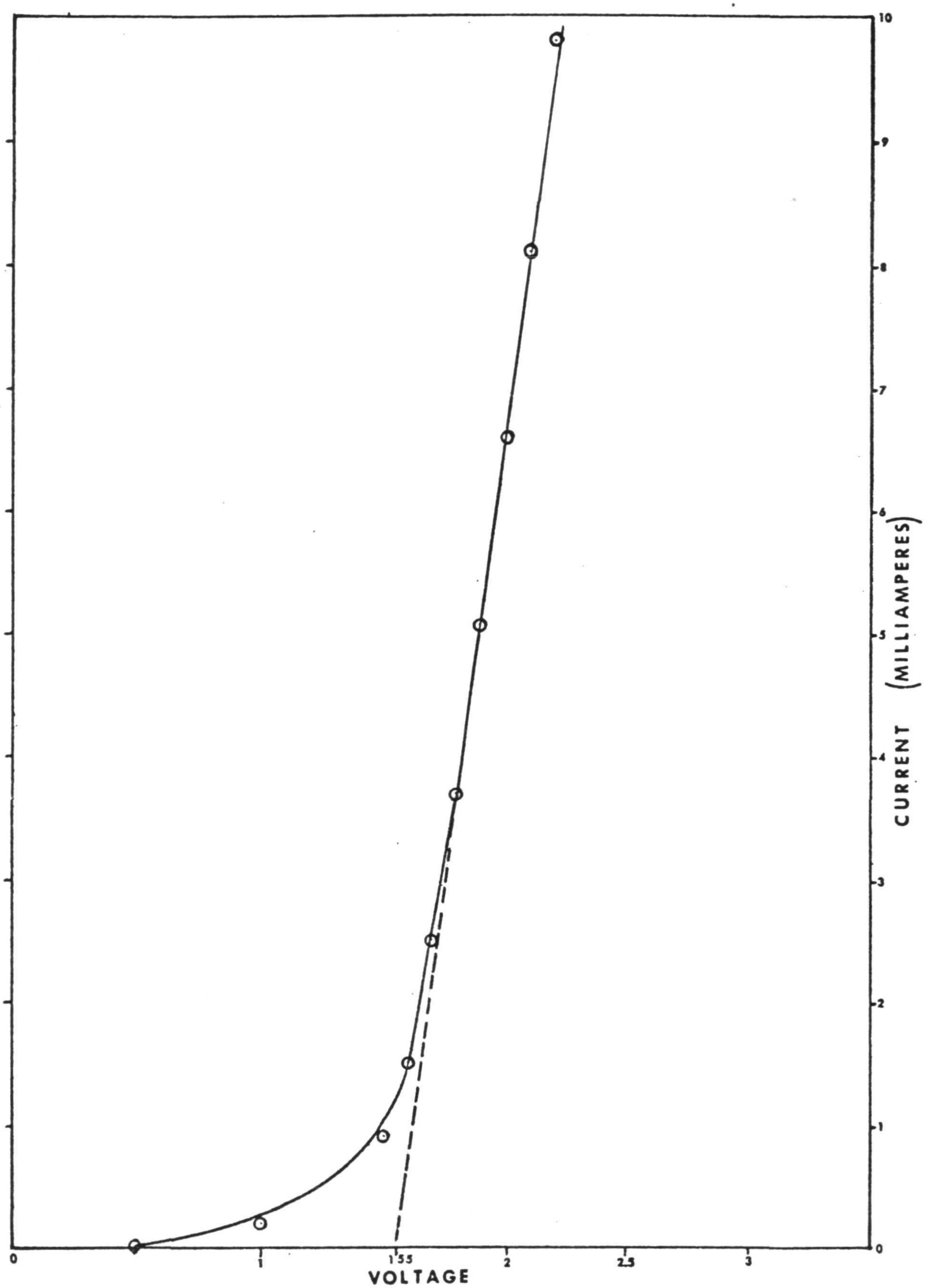


Figure 24. Current Versus Voltage At 1-Inch Electrode Separation- 5% Plating Solution.

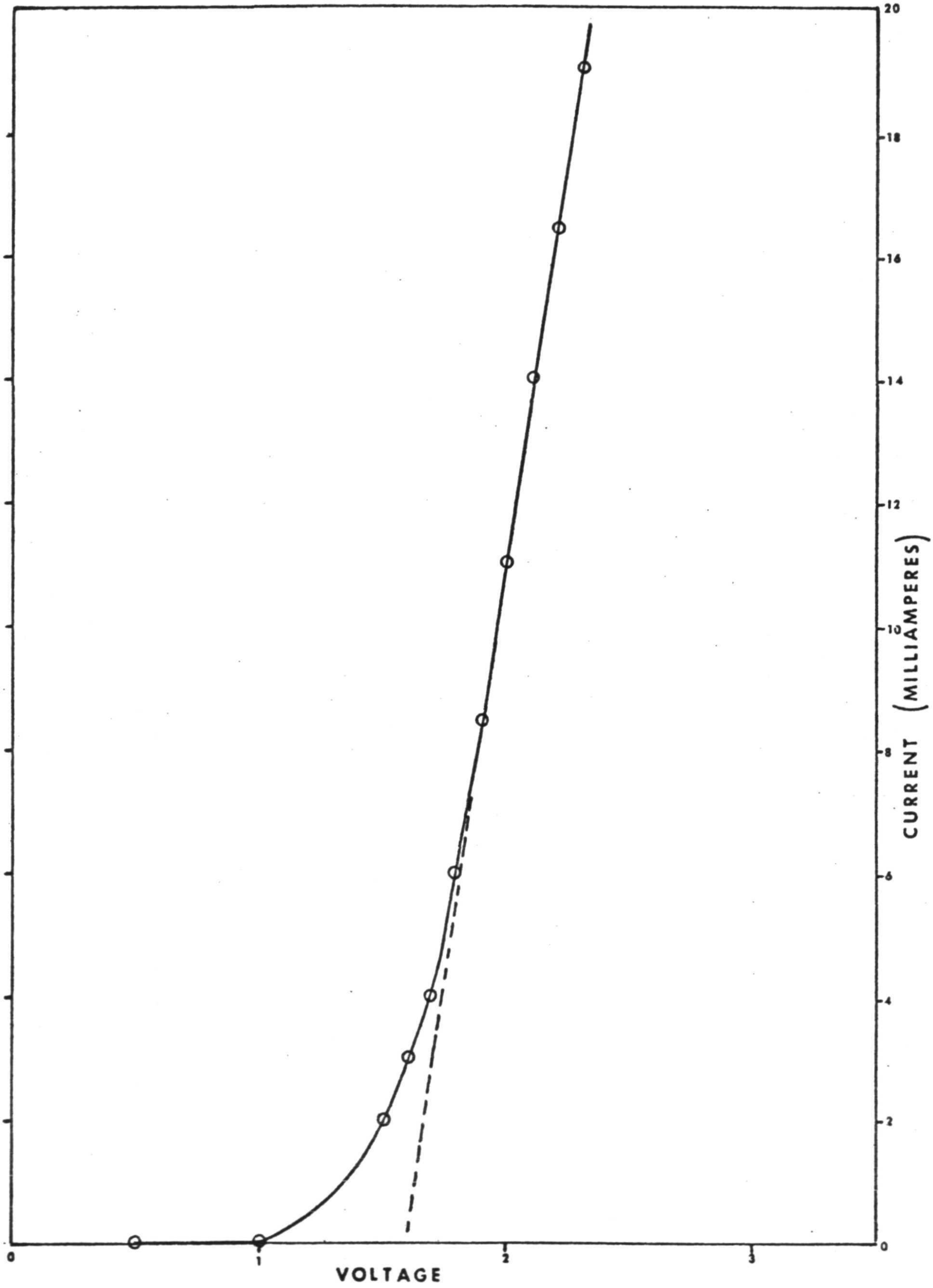


Figure 25. Current Versus Voltage At 1-Inch Electrode Separation-10% Plating Solution

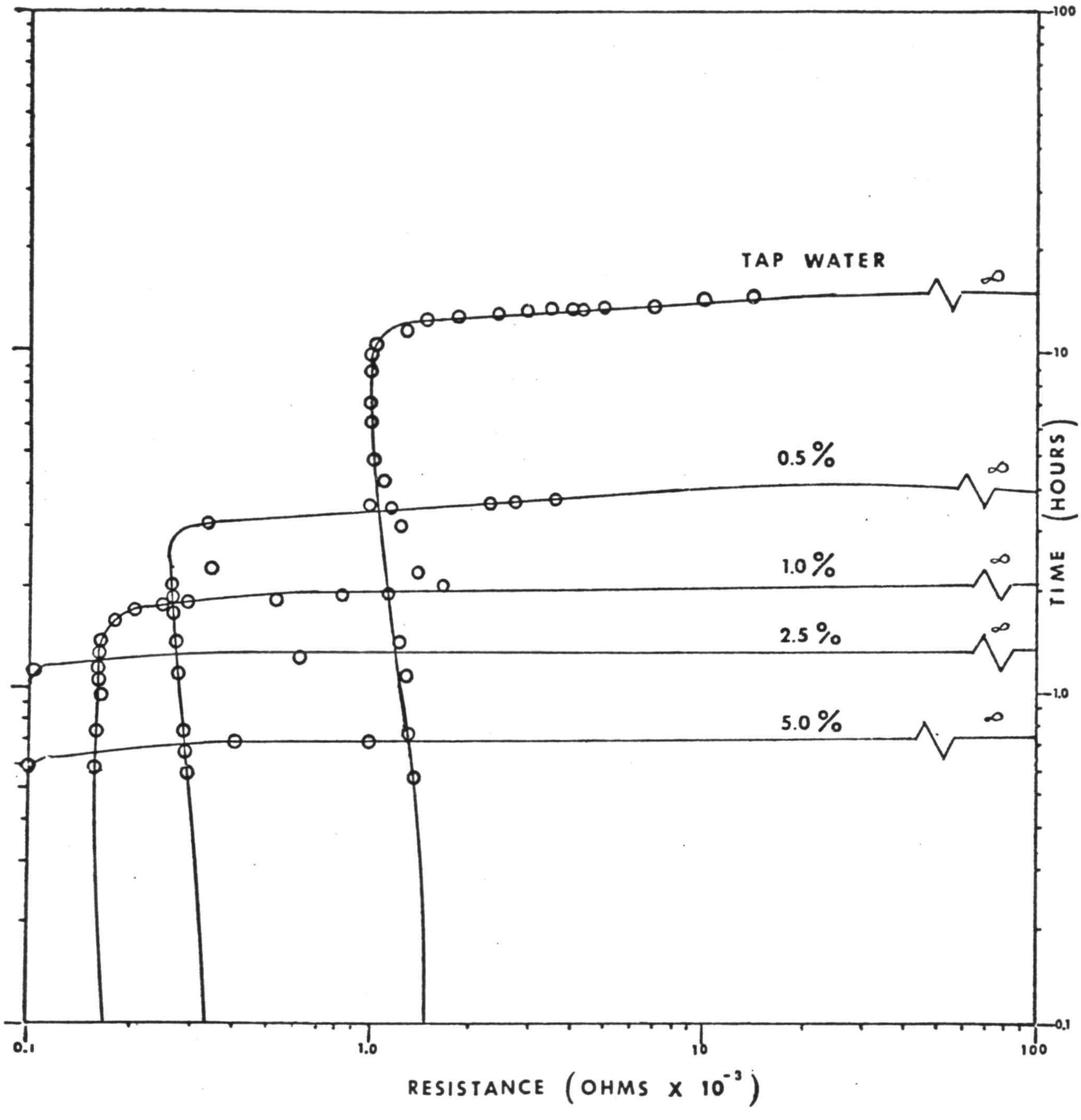


Figure 26. Resistance Versus Time For Five Electrolyte Concentrations At 10 vdc

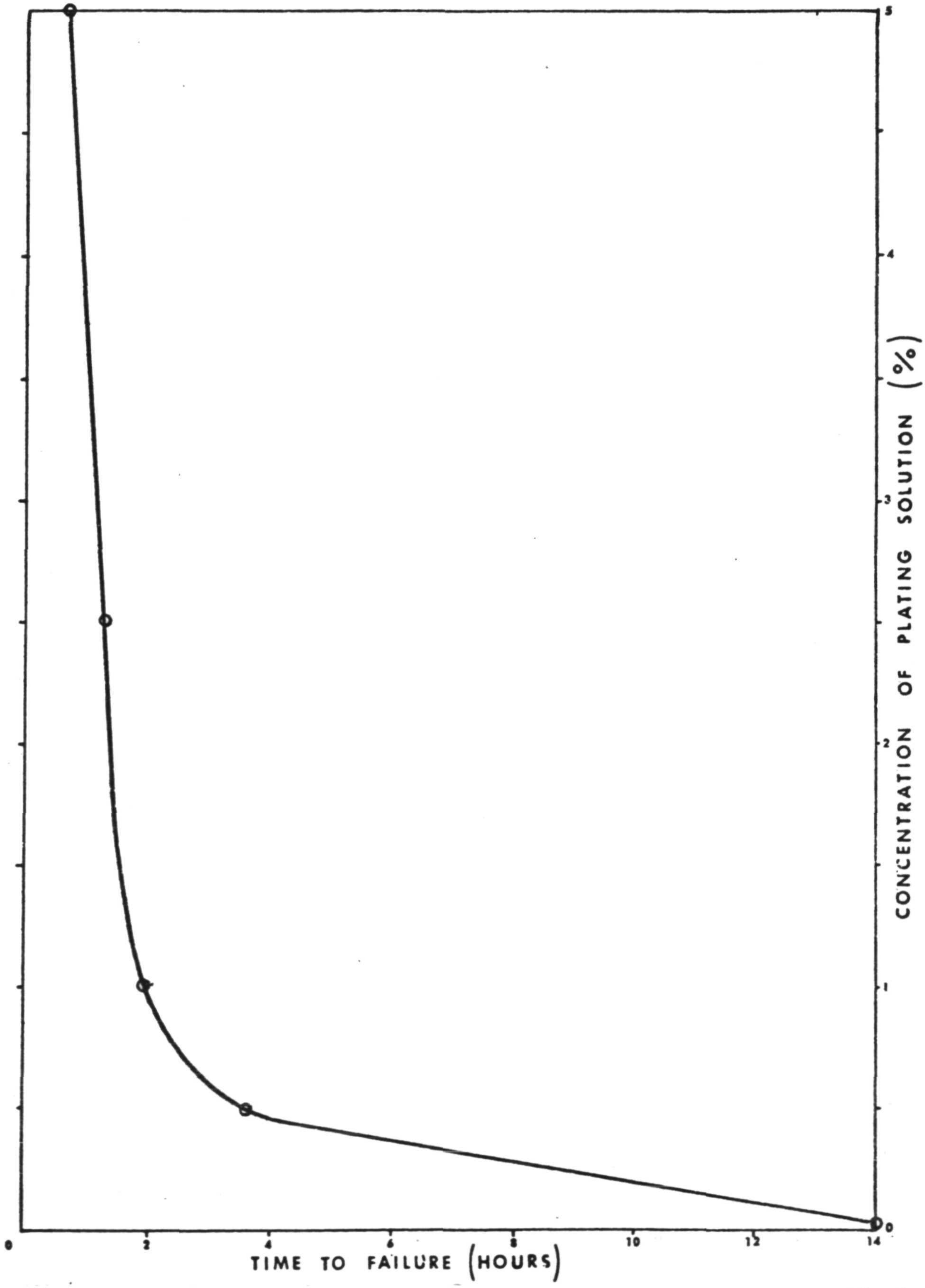


Figure 27. Time To Failure Versus Plating Solution Concentration At 10 vdc

A similar treatment of time-to-failure as a function of voltage levels for 10, 2, 2.5, 2.0, 1.5, 1.25, 1.0, and 0.5 volts was started, but the lower voltage tests (1.25 volts and lower) show no signs of failure after more than 1,000 hours. Figures 28 through 35 illustrate the time/resistance plots for these individual tests at each voltage level. The first series of tests of this type (figures 16 through 21), described earlier, were carried out under static conditions without stirring to simulate the resistor conditions. The tests now described were stirred continuously to avoid concentration gradients within the cell. The 10, 5, 2.5, 2.0, and 1.5 volt tests were run to failure within the available time frame. Thus, figure 36, which is a plot of time-to-failure versus voltage, reflects only these higher voltage levels. The voltage threshold (in the sense of a decomposition potential) is again evident in figure 36. The time-to-failure increases exponentially with decreasing voltage below 2 volts. The cell circuit opened in only 20 hours at the 2 volt level; whereas 192 hours were required to fail the cell running at 1.5 volts. While these time-to-failure data are not directly relatable to the actual resistor, they do predict the relative effect of voltage on service life.

A portion of this study was directed toward explanation of the stabilizing tendencies of the drifting resistors. A general pattern observed in the test program has been an initially high rate of drift with time, which levels off after 50 to 100 hours to a small and nearly linear drift rate. Depletion of copper sulfate complex, as well as water electrolysis, have been suggested as factors responsible for the drift stabilization. An electrolytic cell with 0.5 percent plating solution was operated at 30 vdc while periodic small samples of the solution were taken for copper (Cu^{+2}) analysis. The graph shown in figure 37 shows both copper concentration and resistance plotted as a function of time. The resistance decreases through the first four hours of the test, during which time the copper concentration has decreased to nearly zero. Obviously, if depletion of the copper sulfate electrolyte is to be a governing factor in the conductivity changes in the cell, the resistance should increase with copper sulfate depletion. This is not the case. From a chemical viewpoint, one should not really expect a substantial change in conductivity (and subsequent change in resistance), since each Cu^{+2} ion, removed from solution by reduction on the cathode, would be replaced by Ni^{+2} or Cr^{+3} from anode dissolution as a counter-ion for the sulfate anion which is not removed by oxidation. The conductance values of these metal ions in solution are similar and replacement of one with another should not significantly change the overall cell conductivity.

The depletion of the conducting medium (water) by electrolysis is considered to be a contributing factor to the resistor drift stabilization. As observed in the electrolytic cell tests, H_2 evolution at the cathode is a primary process in this situation and it can be observed at voltage levels

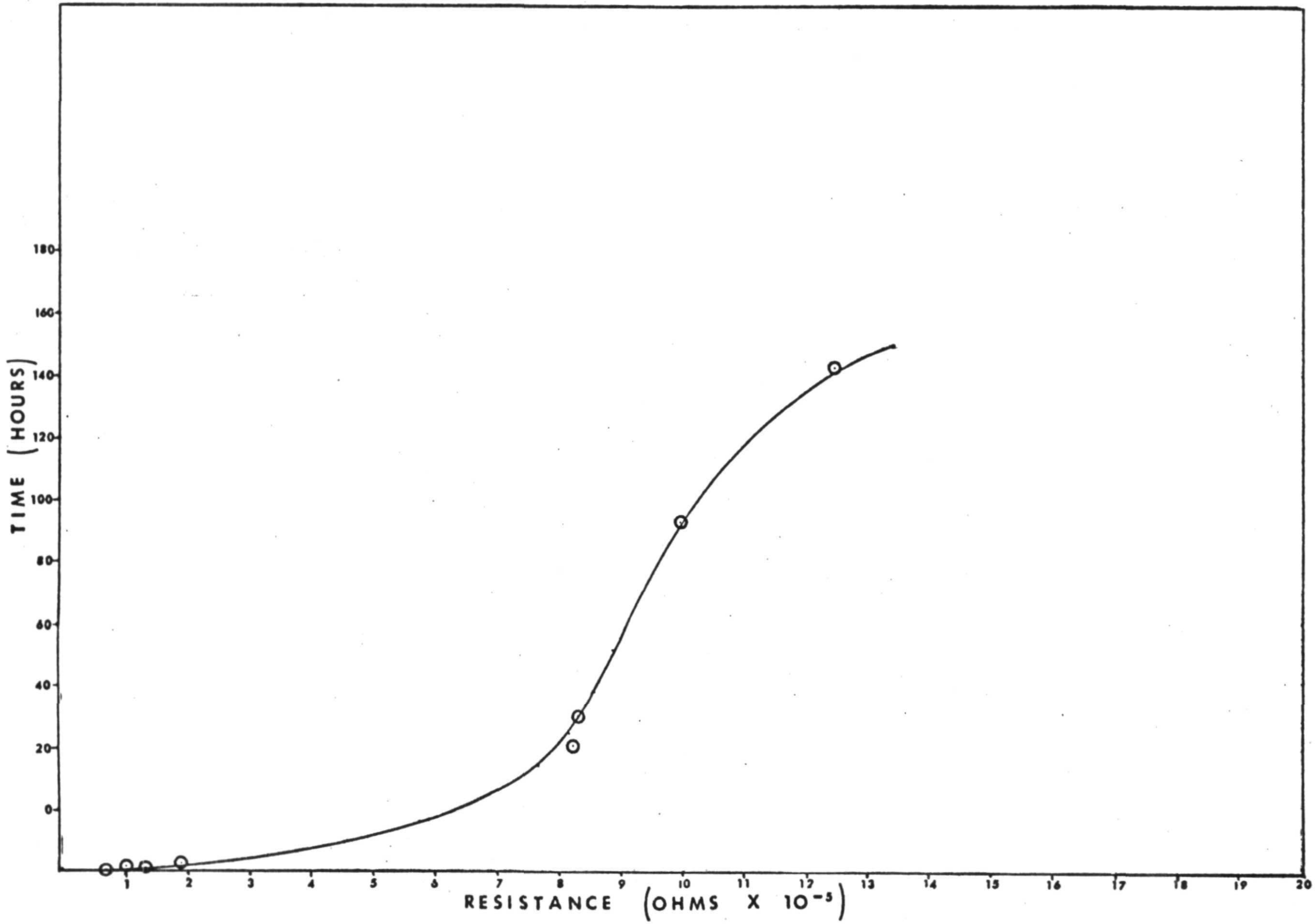


Figure 28. Resistance Versus Time At 0.5 vdc-5% Solution

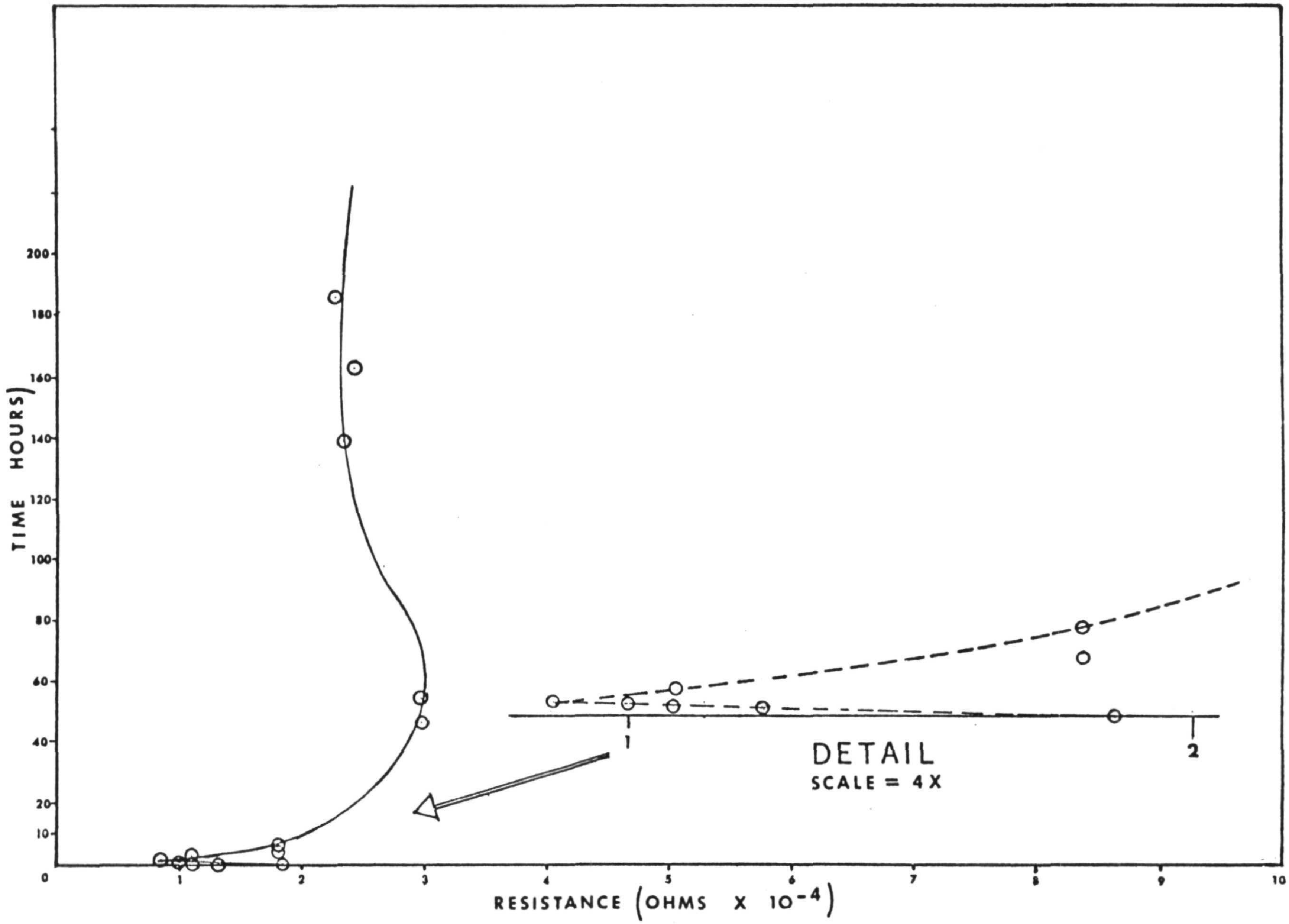


Figure 29. Resistance Versus Time At 1.0 vdc-5% Solution

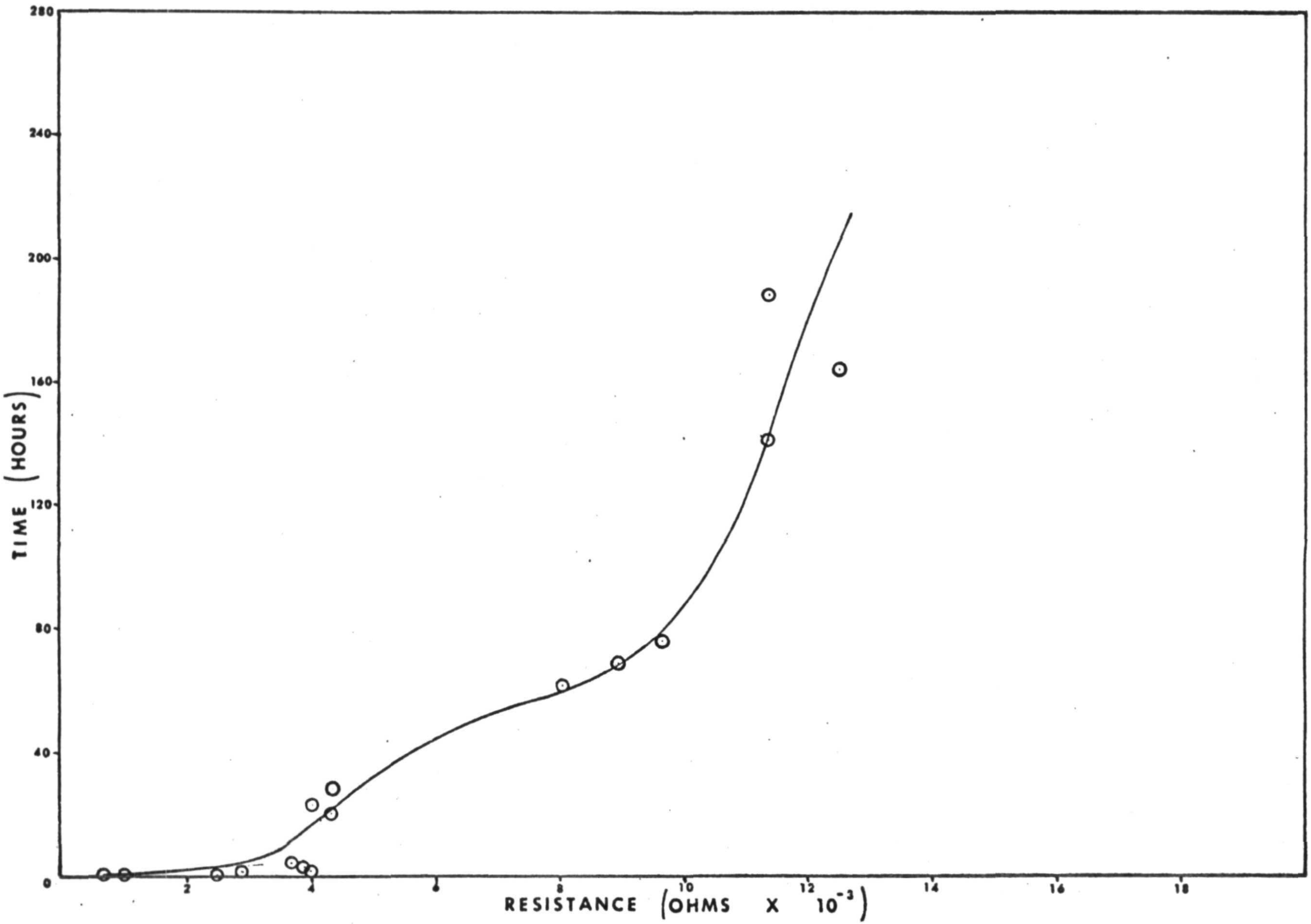


Figure 30. Resistance Versus Time At 1.25 vdc-5% Solution

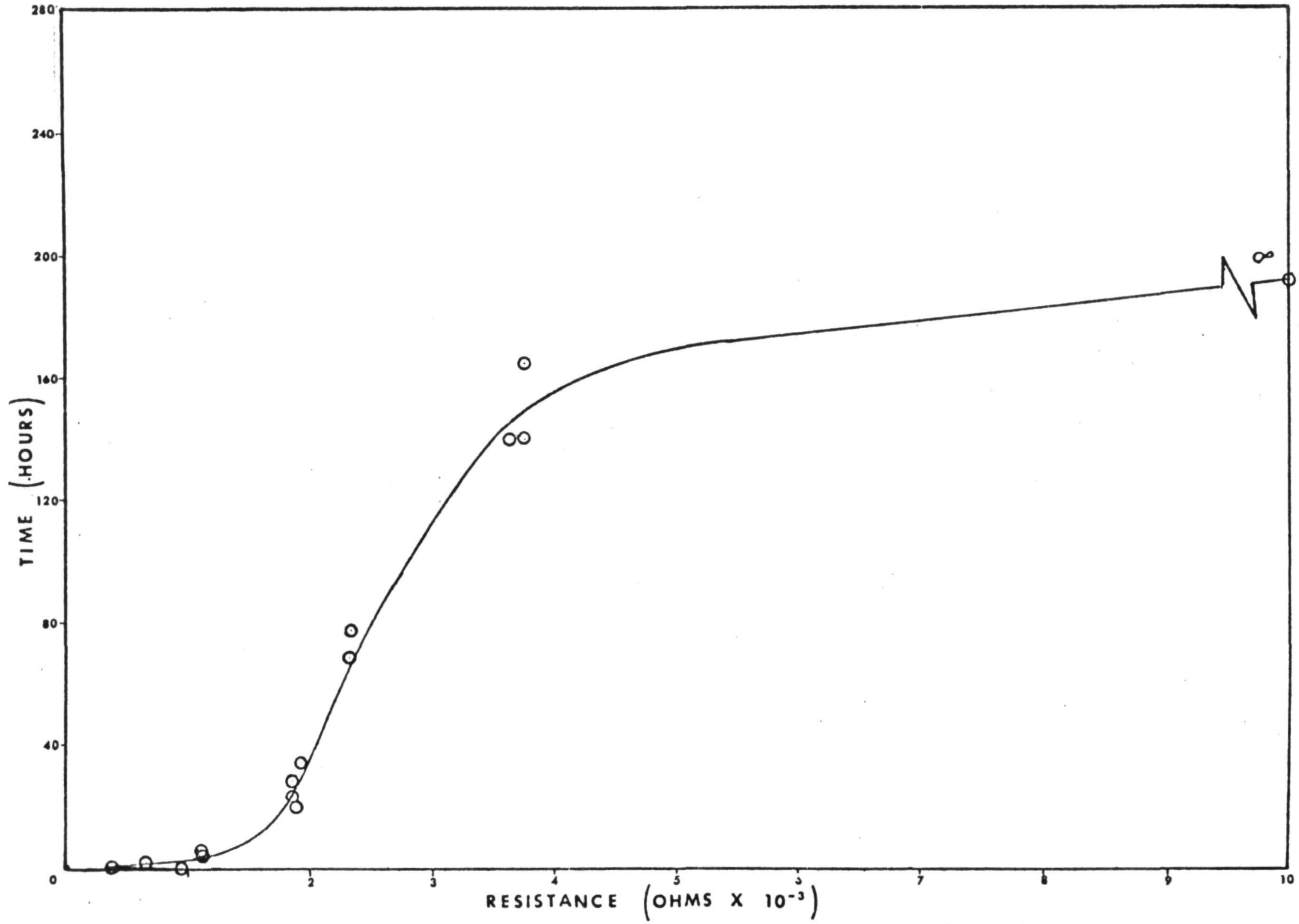


Figure 31. Resistance Versus Time At 1.5 vdc-5% Solution

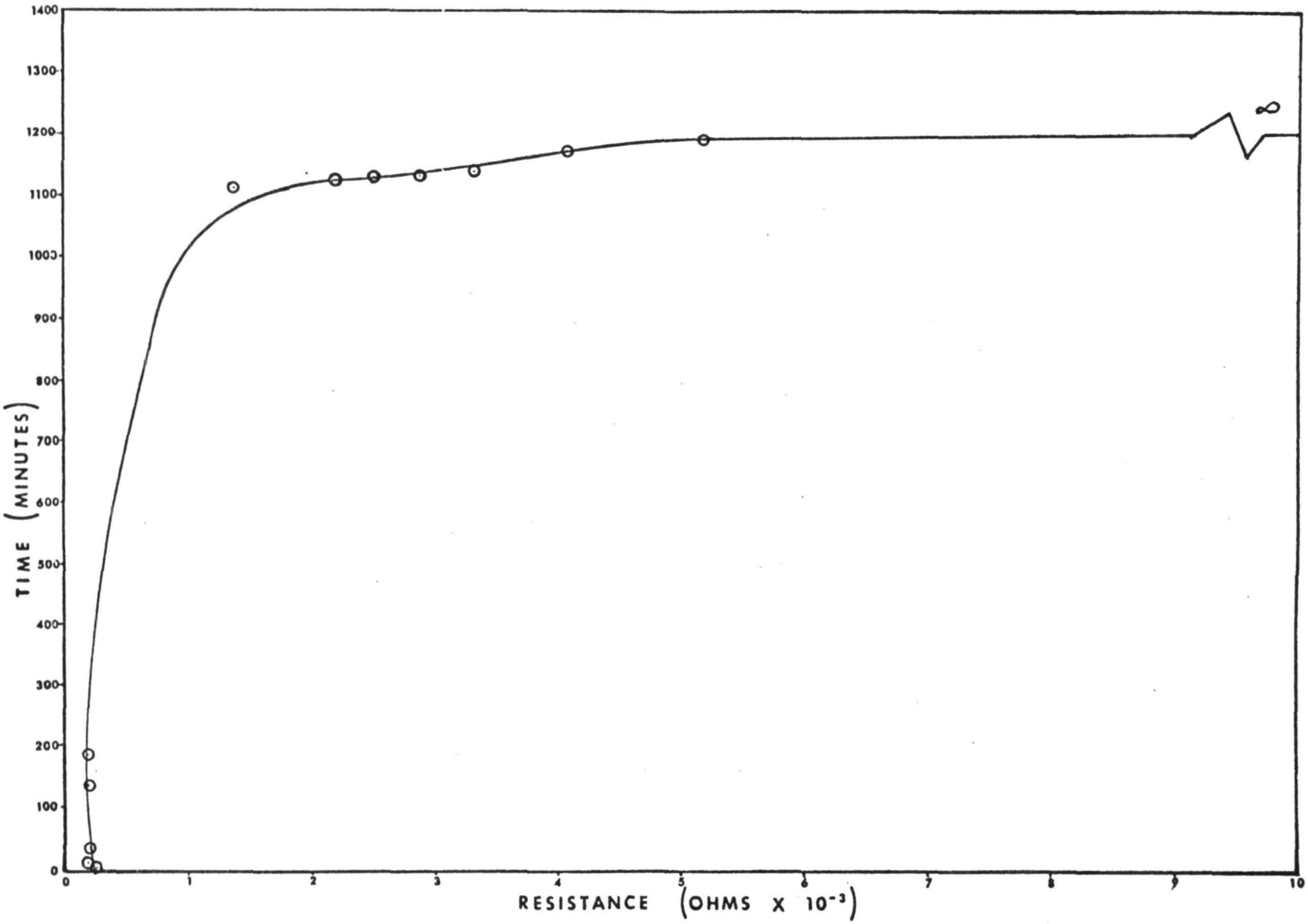


Figure 32. Resistance Versus Time At 2.0 vdc-5% Solution

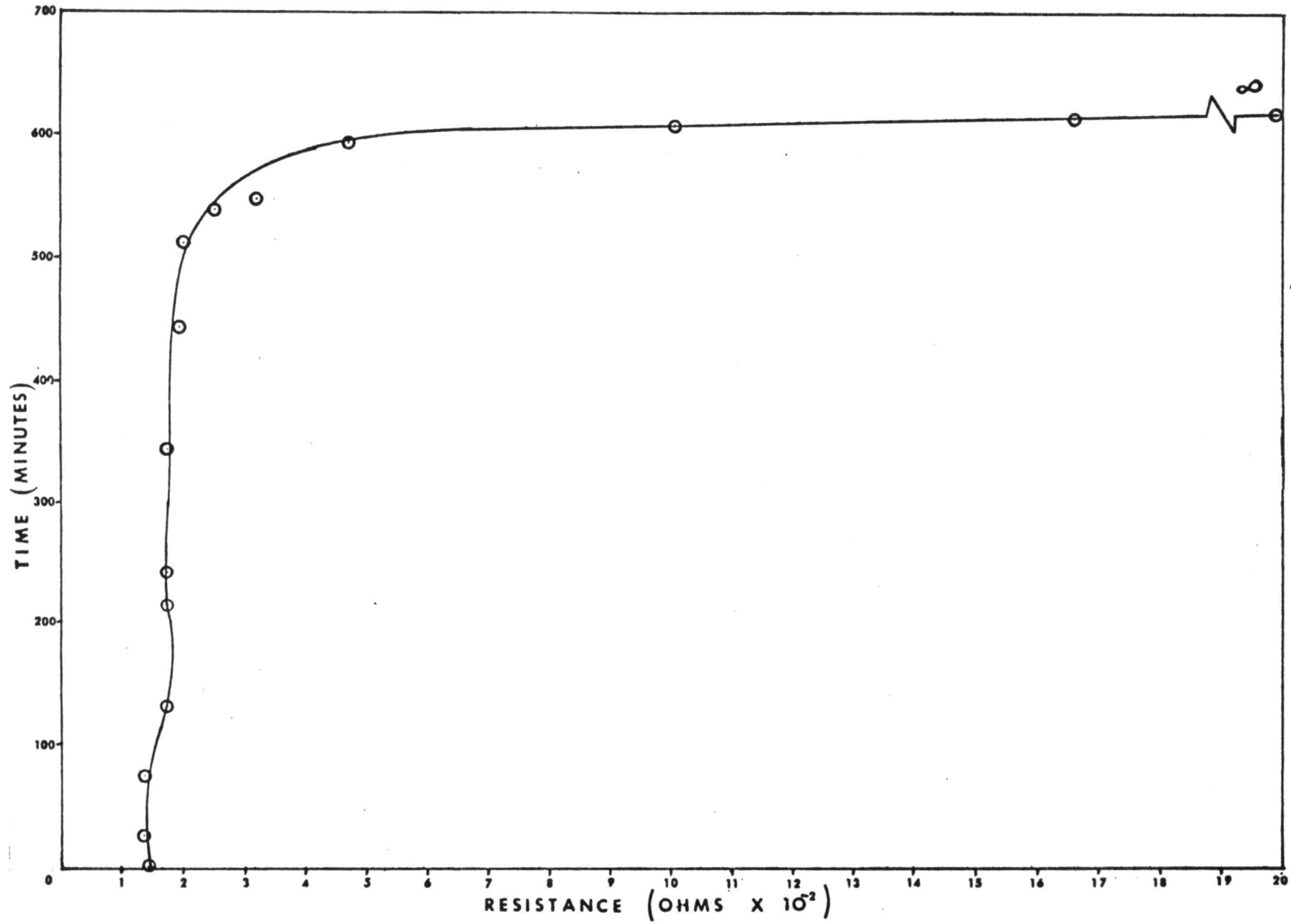


Figure 33. Resistance Versus Time At 2.5 vdc-5% Solution

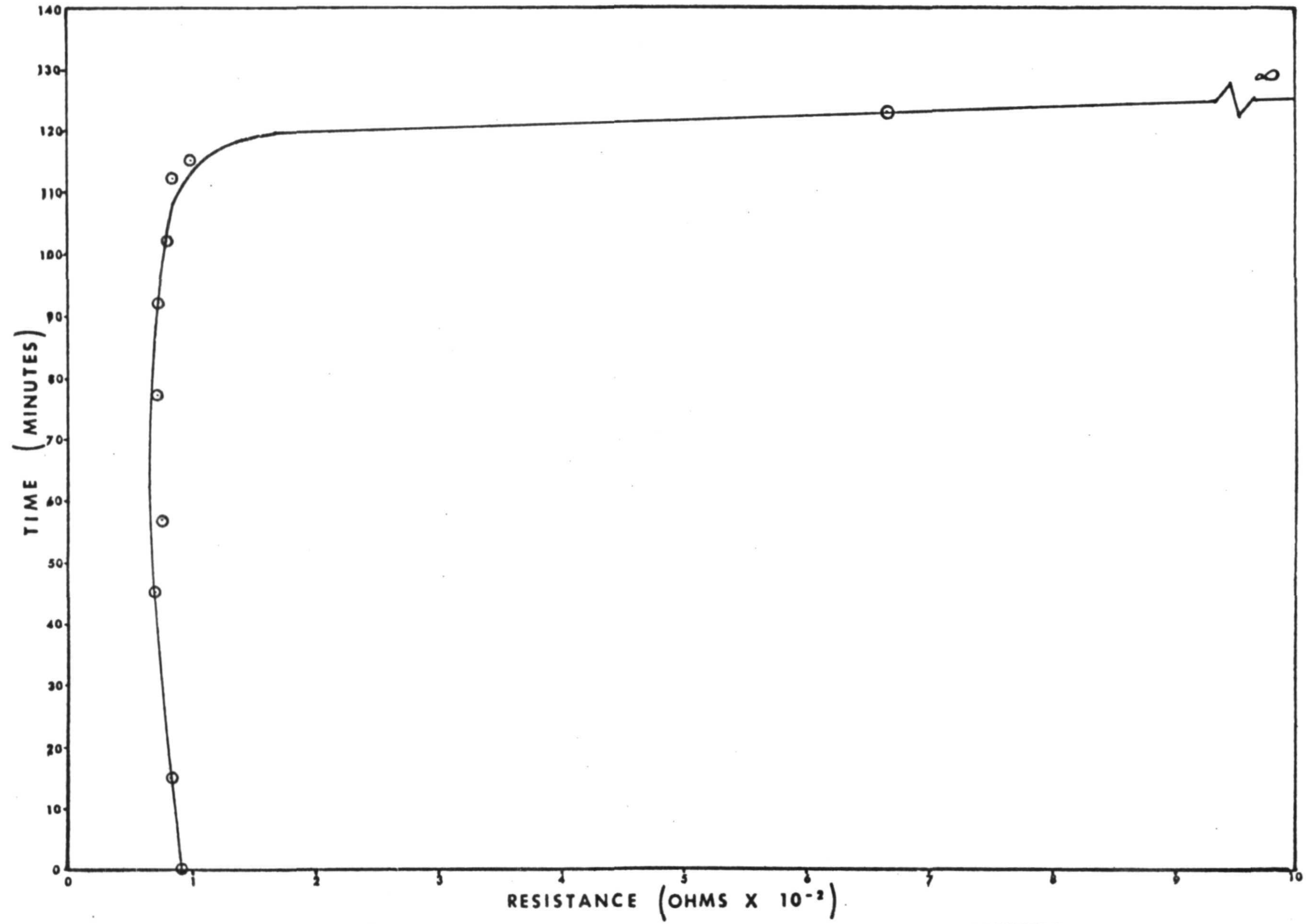


Figure 34. Resistance Versus Time At 5.0 vdc-5% Solution

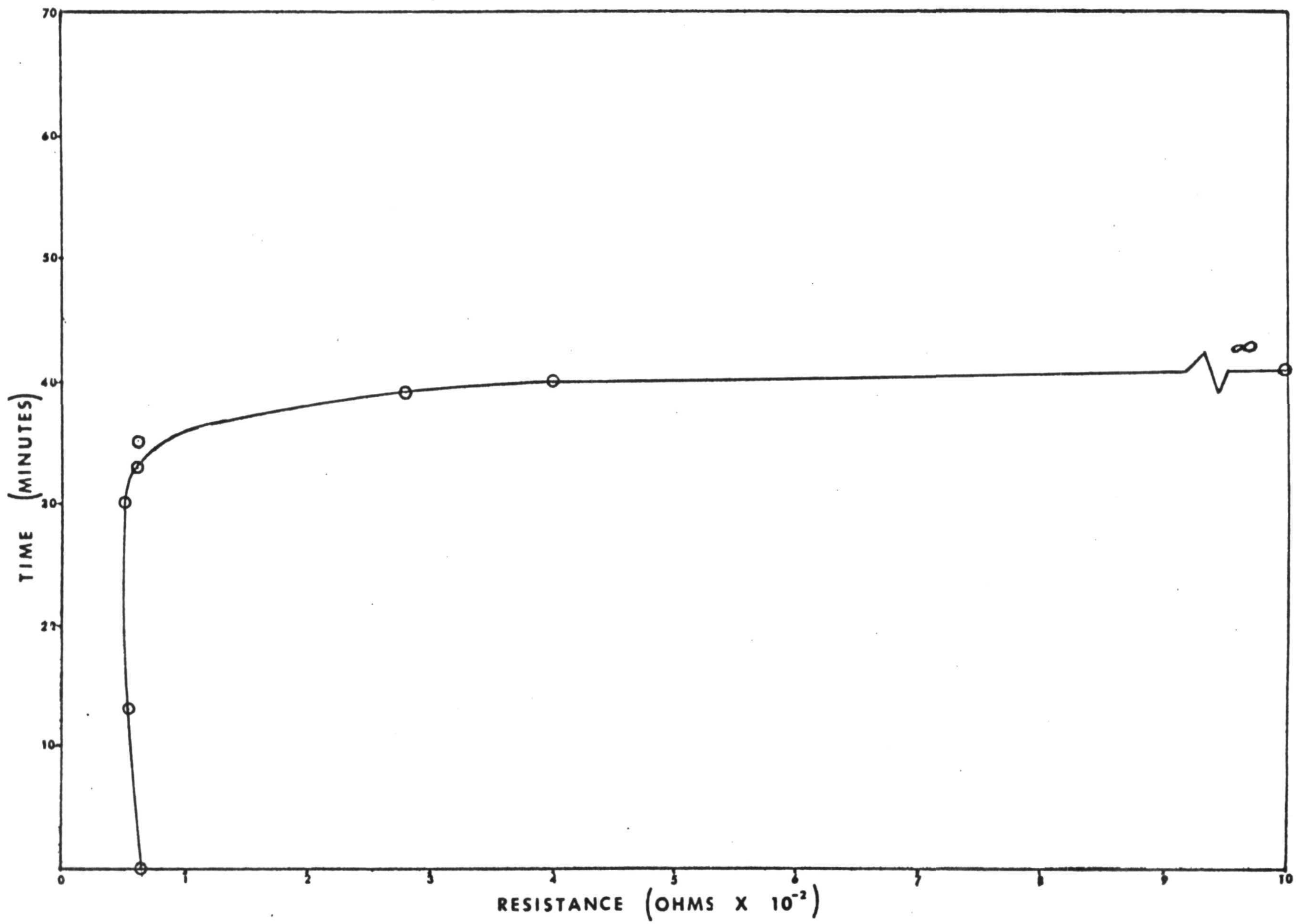


Figure 35. Resistance Versus Time At 10 vdc-5% Solution

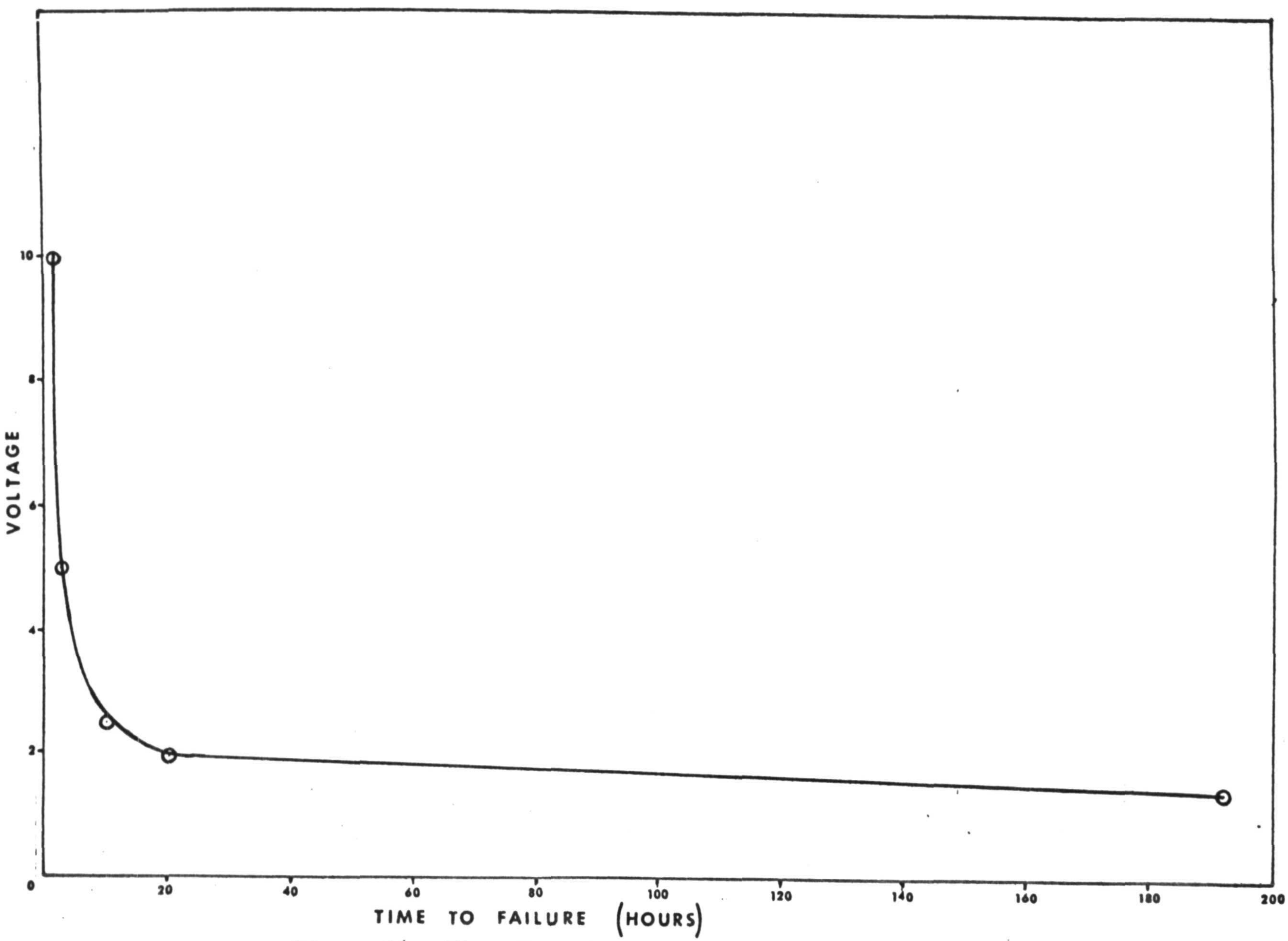


Figure 36. Time To Failure Versus Voltage At 5% Plating Solution Concentration

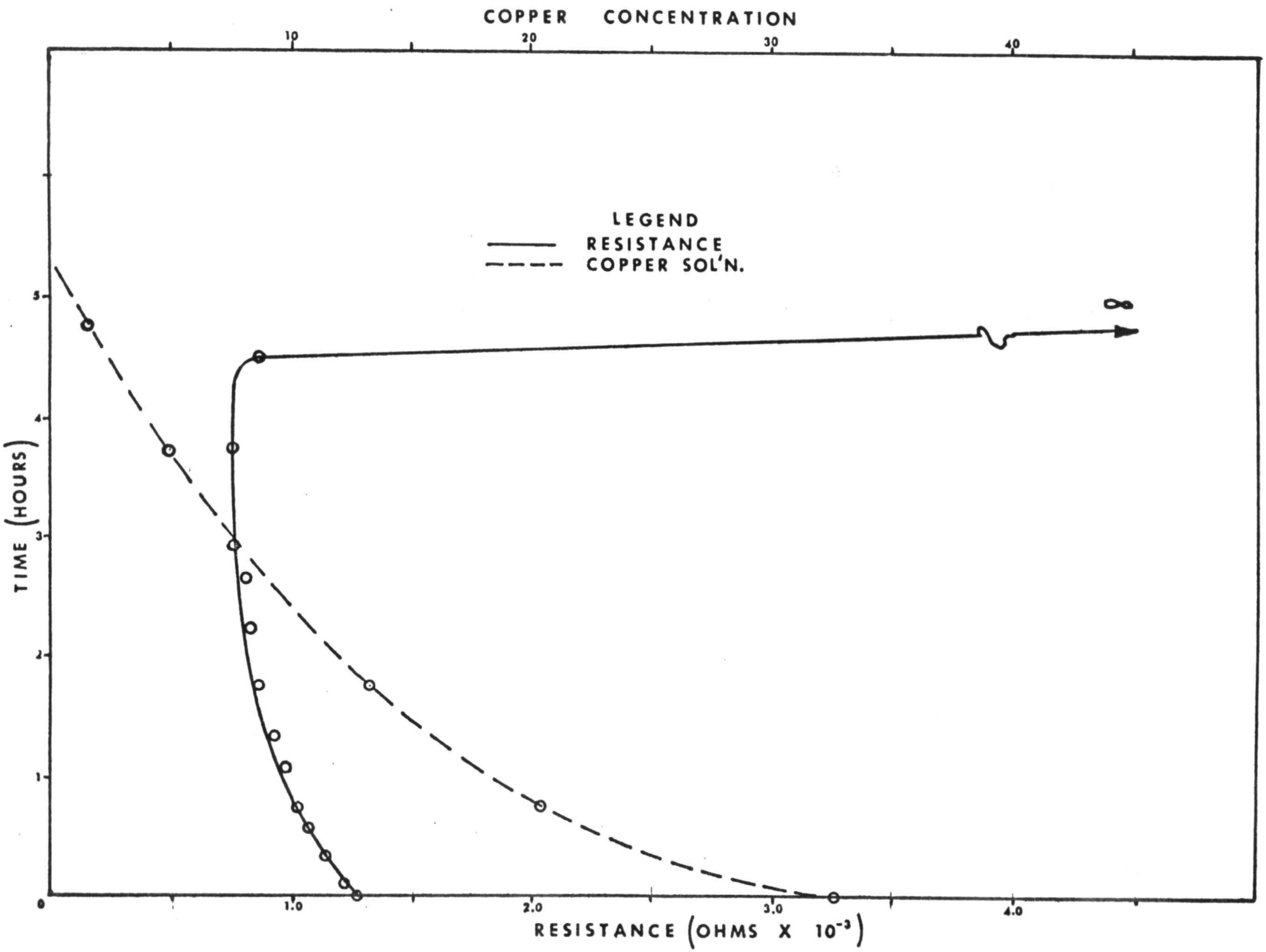


Figure 37. Resistance and Copper Concentration Versus Time At 30 vdc-0.5% Plating Solution

even below that necessary for copper deposition. The H_2 is a product of electrolysis of water, and gradual reduction in the quantity of water available must occur by this process. As the quantity of water bridging the cut between two nichrome bands in the resistor becomes progressively smaller, it should reach a point where there is no longer a continuous electrolyte bridge connecting the electrode. When this occurs, the efficiency of nichrome dissolution from the anode should drop off substantially.

SECTION V. CONTROLLED ENVIRONMENT STUDIES

This section describes the studies made, using both simulated and actual resistors under various environmental conditions, to determine those conditions that are necessary to produce drift similar to that observed in the Vamistor resistors.

A. SIMULATED RESISTOR INVESTIGATION

To facilitate the investigation of the failure mechanism, simulated thin film precision resistors were developed and produced in-house. These resistors were made by vapor depositing NiCr (Nichrome V) films onto Pyrex or ceramic substrates, using a precision mask to provide the necessary conductive path length and spacing. Details of the process are given in Appendix I. Photographs of the two types of resistors used are shown in figure 38.

The primary advantage of using this type of resistor is that it provides the ability to observe the NiCr film under a microscope while the film is being subjected to simulated operating conditions. A secondary advantage is that this resistor configuration is much easier to analyze for damage following active tests.

1. Liquid Electrolyte Tests. The first series of tests with the simulated resistors were simply an attempt to duplicate the damage mechanism observed in the drifting Vamistors. A slide was setup in the microscope, a drop of one percent plating solution was applied to the surface, and a potential of 10 vdc was applied. The NiCr film began eroding immediately from the anode and bubbles were observed forming at the more negative strip. The observed pattern of erosion was almost identical to that observed with the Vamistors. When the polarity of the applied dc voltage was reversed, the reaction observed was identical to the previous test, except that both the direction of erosion and the consequent damage pattern was reversed.

A third test was conducted in this series, using the same basic setup, but with a switch added to allow polarity reversal without removing

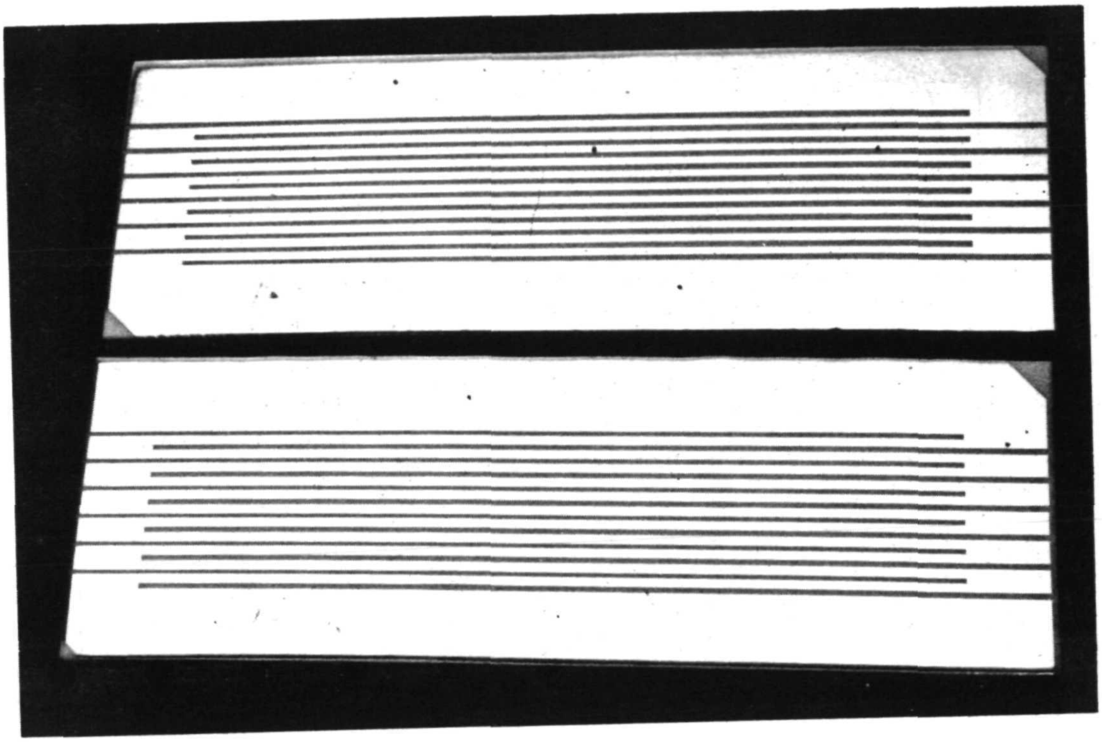


Figure 38. Vapor Deposited Thin Film Resistors

leads. The voltage was applied for 2 minutes, then reversed, and continued for 2 minutes. Damage occurred to both films with an almost identical erosion pattern, except that the conductive film edge which was attacked last was slightly smaller due to the increased gap. Photographs of these three runs are shown in figures 39, 40, and 41.

For information, this test was repeated using tap water and then distilled water in place of the plating solution. The results were essentially the same, although a slightly higher voltage was required for tap water and approximately twice the voltage was required for distilled water.

2. Dried Electrolyte Humidity Tests. The previous tests were conducted using a liquid electrolyte (one percent plating solution). Realistically, it would be assumed that the actual resistor would contain a dried electrolyte (plating solution residue) and some humidity which could produce the required electrical path. Consequently, a second test series was set for just these conditions.

A slide was set up on the microscope stage, with a dried plating solution (one percent) on its surface and 10 vdc applied. Water vapor was directed at the dried spot from a tube connected to a container of boiling water. No action was observed until the water vapor impinged on the dried plating solution, then the eroding action on the NiCr film was the same as seen in previous tests, continuing as long as water vapor was present.

3. Voltage Tests. This test setup was simple, easily controlled, and produced directly observable results. For these reasons, a series of three tests were planned to determine which electrical parameters produced damage. These tests were:

a. 60 Hz ac

b. 400 Hz ac

c. Pulsating dc

The results of these tests indicated that all voltages types would cause damage to the conductive film; however, the amount of damage produced did vary. For the same period of time at the same applied voltage, the damage was, in descending order of severity:

a. dc

b. Pulsating dc

c. 60 Hz ac

d. 400 Hz ac

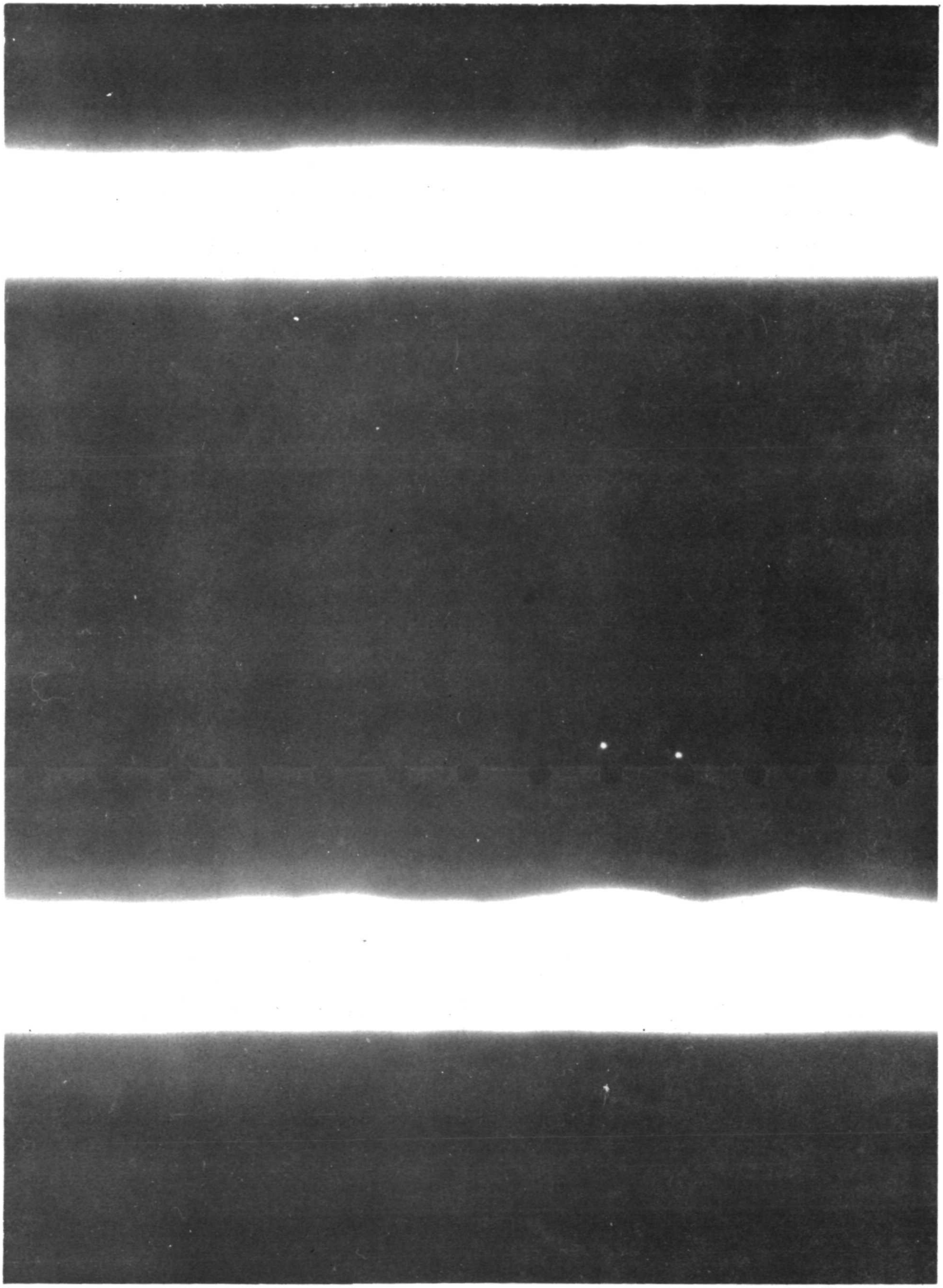


Figure 39. Liquid Plating Solution and dc

Figure 40. Liquid Plating Solution dc, and dc Polarity Reversed

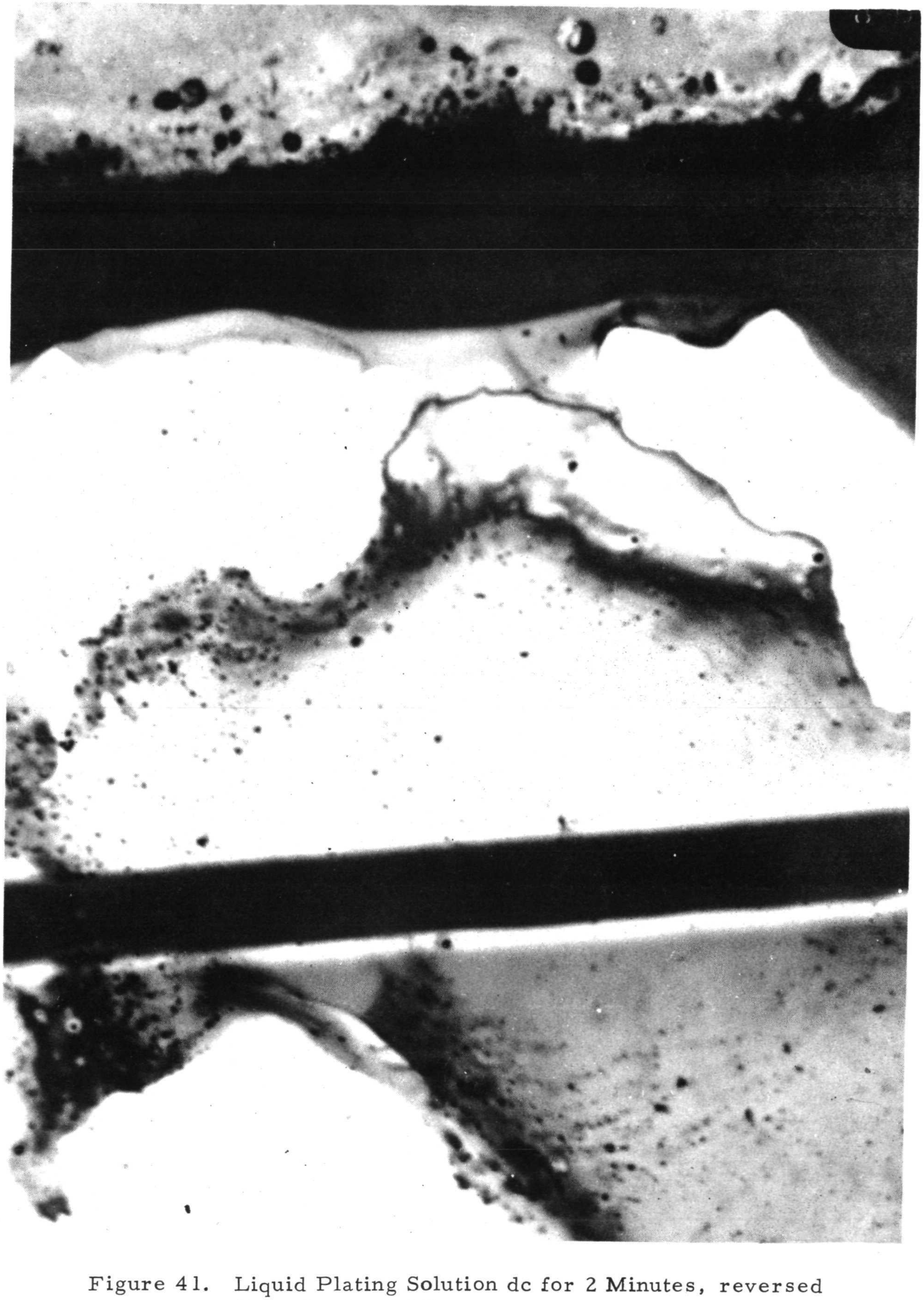


Figure 41. Liquid Plating Solution dc for 2 Minutes, reversed Polarity for 2 Minutes

Figures 42, 43, and 44 show photographs of damage resulting from voltage types a, b, and c, respectively.

The particular value of this last series of tests was in defining the types of tests needed on actual Vamistors. With this background information a series of tests could be planned in order to provide information on what could be expected from Vamistor resistors installed in flight hardware under various types of operating voltages.

B. PRELIMINARY TESTS ON VAMISTORS

1. Vacuum Tests. Since all previous tests had indicated that a plating solution residue and humidity had to be present to produce a drifting resistor, two tests were conducted to ascertain if removal of the humidity (by evacuating the resistor) would sensibly cause the drifting to cease.

a. Test #1. The first test was on a single resistor (5 K Ω) whose resistance had been changing consistently. The resistance of the unit was monitored for 190 hours. At this point, a 0.030-inch hole was drilled in one endcap, and the resistor was placed in a vacuum chamber which was then evacuated. A plot of resistance change as a function of time is shown in figure 45. The resistor changed by 2.6 percent in 190 hours when sealed and only 0.4 percent after 250 hours of vacuum exposure.

b. Test #2. For this test, three resistors with a known history of drifting were selected. The resistors had a 0.030-inch hole drilled in each endcap and they were placed in a test chamber with 100 percent relative humidity. With voltage applied, the resistors drifted 0.6, 0.25 and 0.1 percent over 160 hours. At this point, the water vapor was pumped out of the chamber. All three resistors stopped drifting. A plot of resistance change of one of the resistors as a function of time, indicating the point at which the chamber was evacuated, is given in figure 46.

Both of these tests tended to confirm the hypothesis that water is a requisite for operation of the damaged mechanism.

2. Effect of Plating Solution Concentration. The other variable which obviously should have an effect on drift is the concentration of the plating solution residue. A higher concentration should provide a greater number of ions and, therefore, should produce greater damage (greater change of resistance) over a given period of time. The following test was conducted to investigate this effect.

Five Vamistor resistors were selected and 0.030-inch holes were drilled in each endcap. Two resistors were retained as controls and the

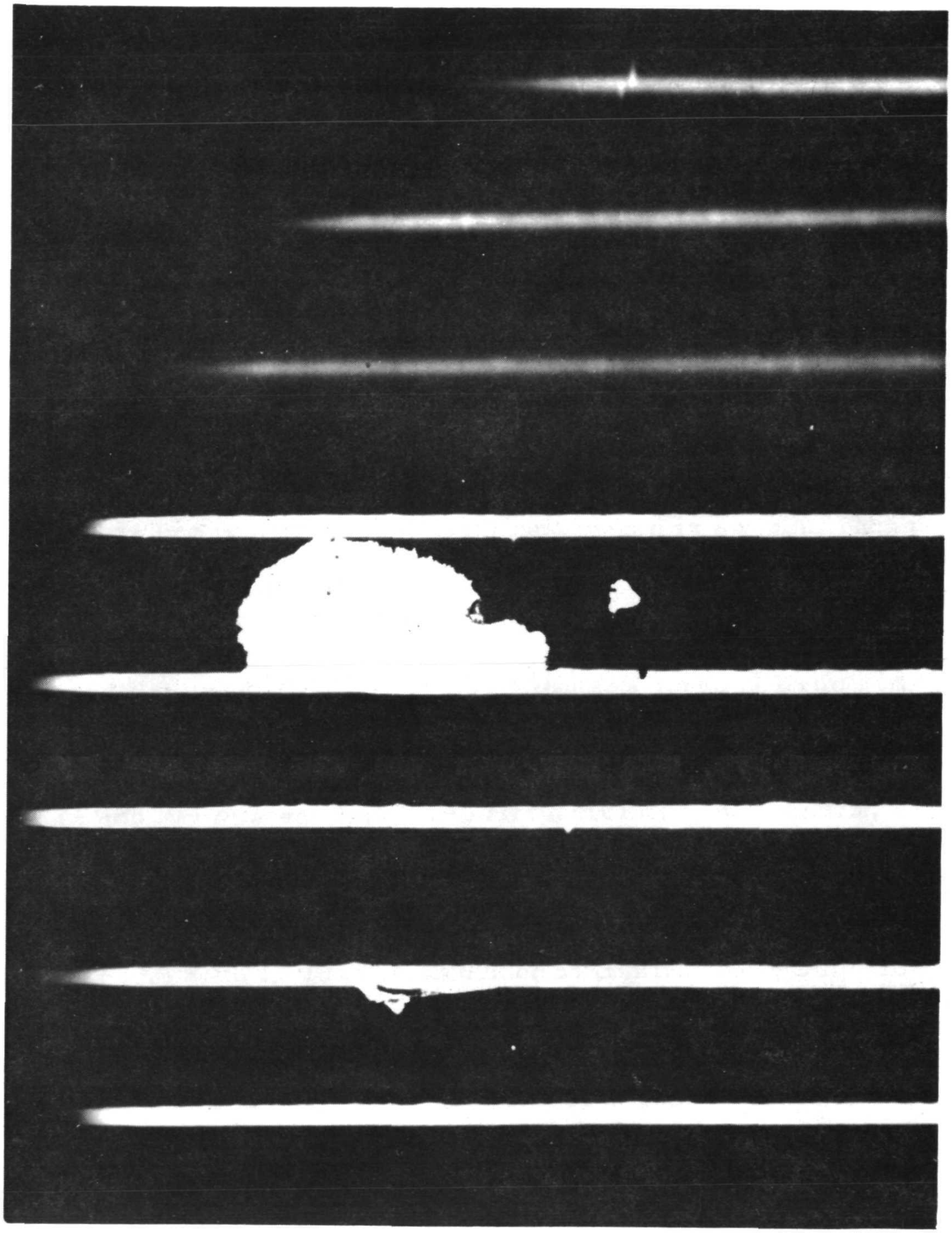


Figure 42. Dried Electrolyte, Water Vapor, and dc

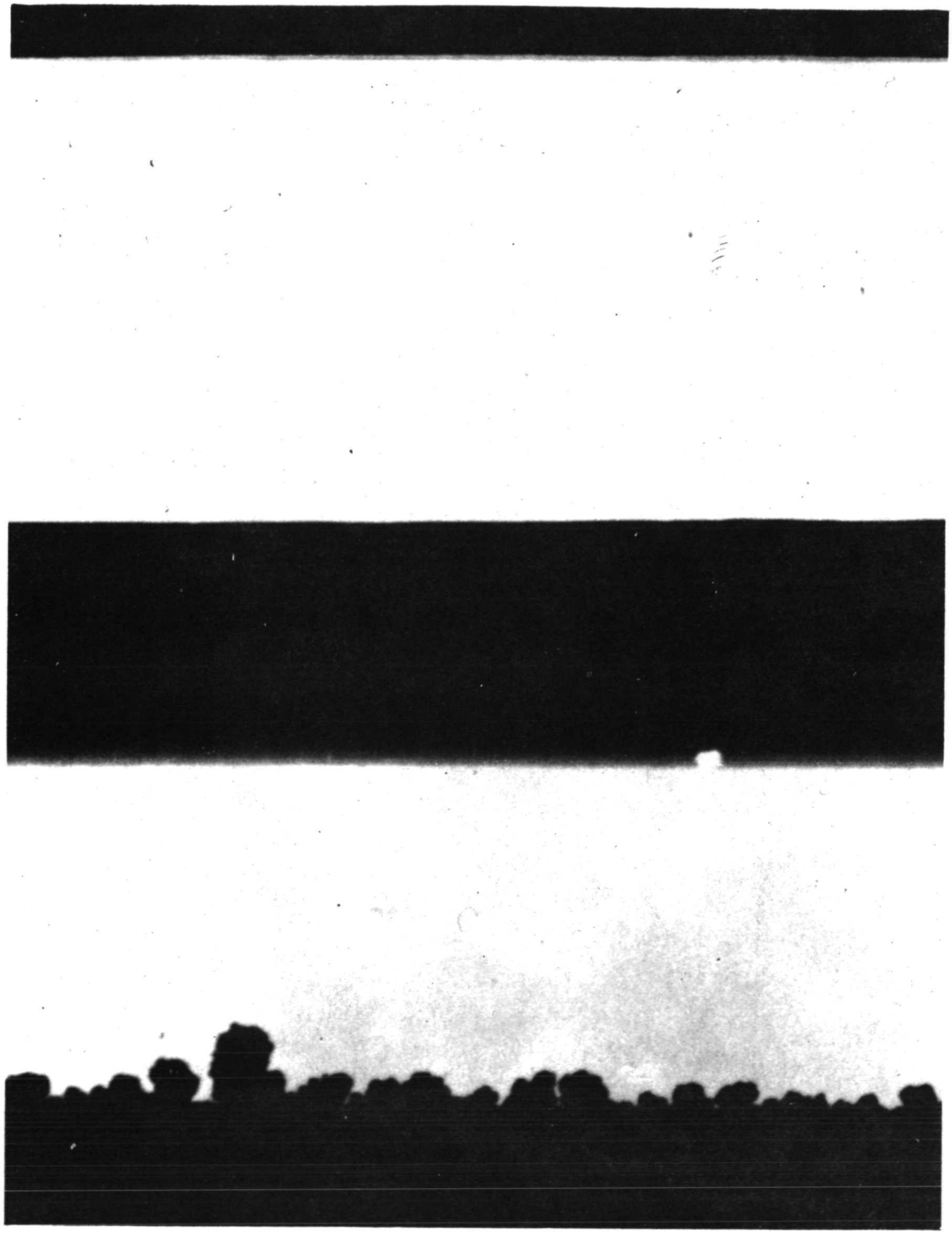


Figure 43. Dried Electrolyte, Water Vapor, and Pulsating dc

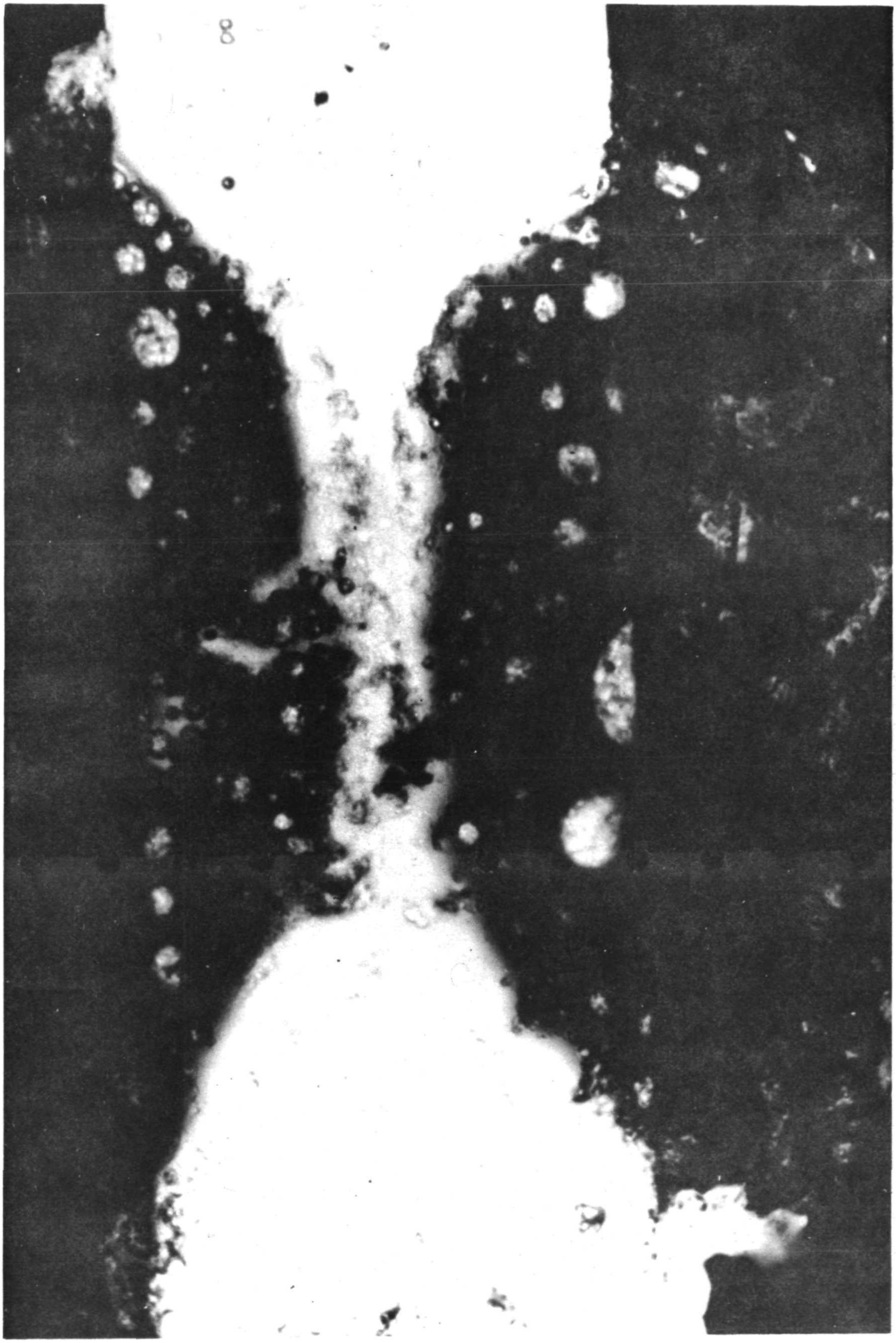


Figure 44. Dried Electrolyte, Water Vapor, and 60 Hz ac

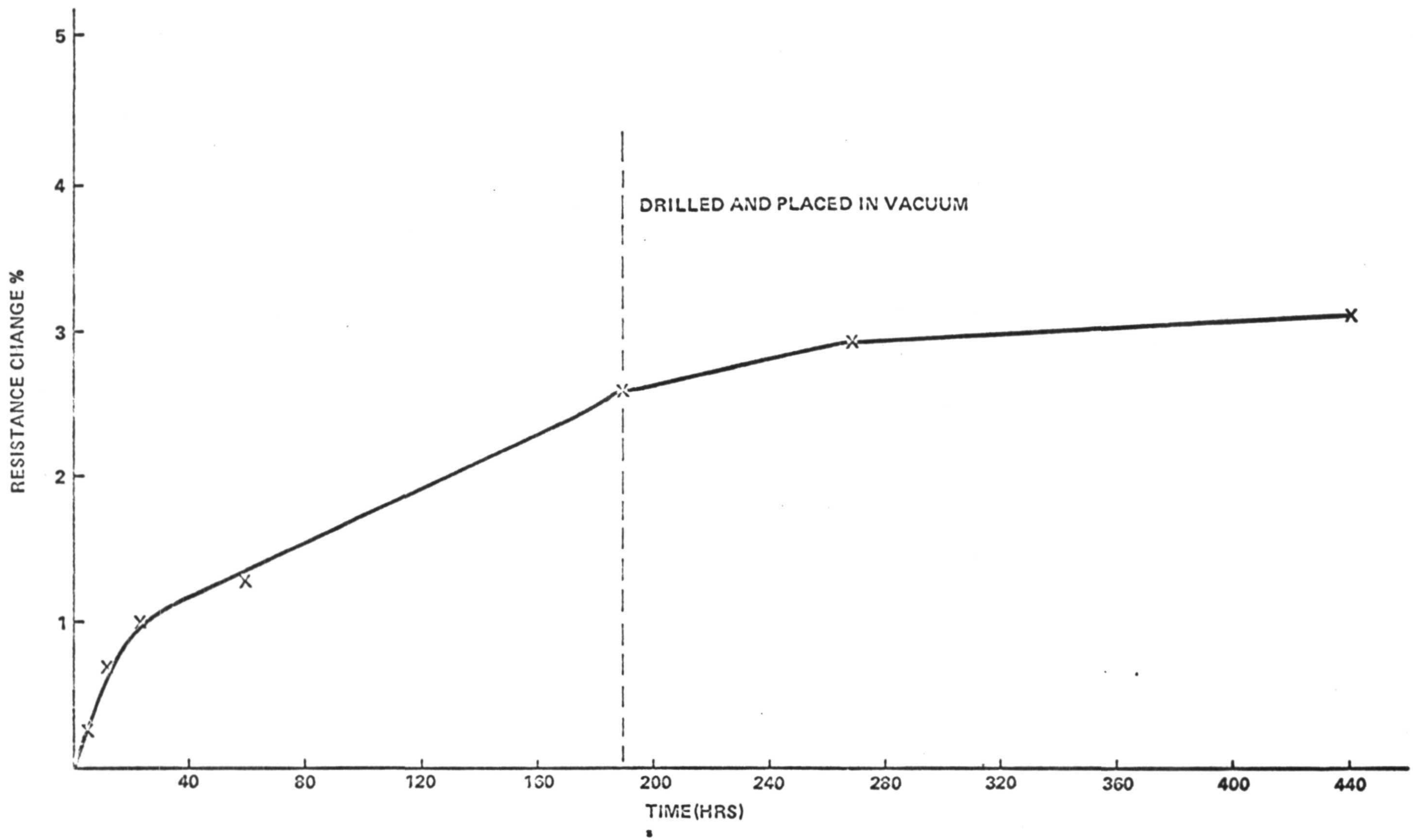


Figure 45. Effect of Removing Humidity From Drifting Resistor-
5K Resistor At 2 Volts

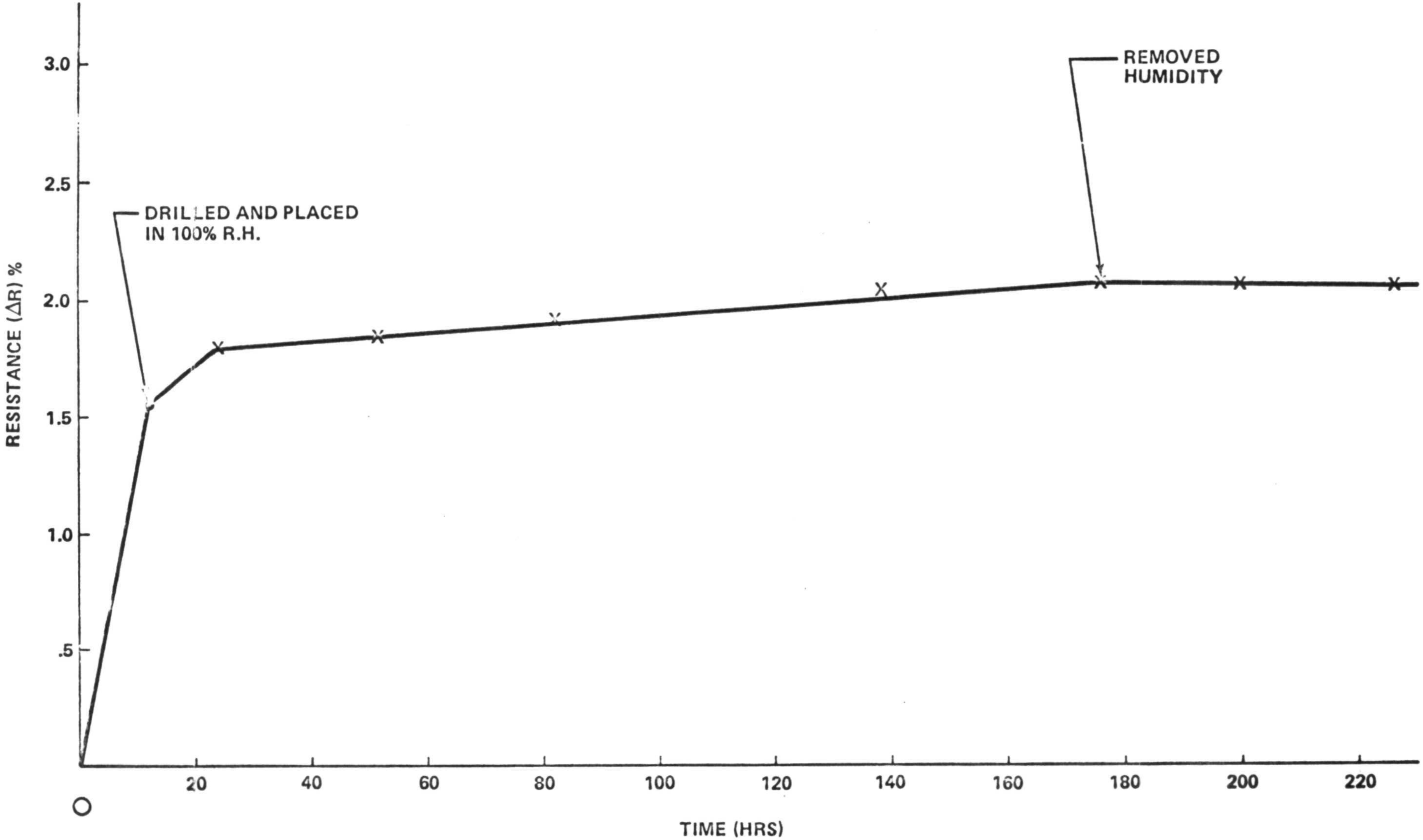


Figure 46. Humidity and Drying Test on Vamistor Resistors

remaining three were injected with 0.75, 0.25, and 0.1 percent plating solution, respectively. The resistors were dried for 24 hours and then placed in a chamber with 100 percent relative humidity.

The results of this test were inconclusive. Introspection into the conditions of the test indicated the probable reason for the problem. Production run Vamistors were selected for this test and each contained an unknown quantity of plating solution residue. So, even after injecting a known solution there was no way of determining the actual quantity of dried plating solution present, since there was no way of knowing how much plating solution was present originally.

This test is being repeated using non-hermetic sealed Vamistor resistors which contain no plating solution residue. The results of this test will be presented in the final report.

3. Plating Solution Drying and Moisture Absorbtion Tests. Since it had been well established that a combination of plating solution residue and water vapor was required to produce a drifting resistor, two tests were planned to check the nature of the deposit in a production Vamistor. The first of these tests was simply to take a given quantity of plating solution, place it on a continuous weighing balance, evaporate the water, and see what quantity of residue remained. The second test was to expose the dried residue (still on a balance) to a humid environment and determine what amount of moisture was absorbed and over what period of time. It was thought that these tests would provide some insight into the actual contaminant levels introduced during production operations, since the resistors are dried (vacuum oven) and then exposed to plant atmosphere for some time before applying the endcaps.

a. Drying Test. A quantity of 0.75 percent plating solution, representing the internal volume of a one-tenth watt Vamistor resistor, was placed on the balance pan of a continuous weighing balance. The weight of the plating solution was 105 mg total. The sample lost 29.3 mg in the first hour at ambient temperature (28 degrees). Heat was then applied to the sample and all of the liquid was removed in 15 minutes. The weight of the residue was 0.45 mg or 0.43 percent of the original solution (see figure 47); thus, if a Vamistor of this size was exposed to a rinse bath containing this concentration of plating solution, it could contain on the order of 450 micrograms of residue after it was dried.

b. Water Absorption Test. Sufficient 0.75 percent plating solution was evaporated to produce a residue of 1.9 mg on a balance pan. The balance pan was placed on a continuous weighing balance and the entire assembly was placed in a test chamber with 100 percent relative humidity. A plot of weight versus time is shown in figure 48. The 1.9 mg residue absorbed over 3.0 mg water during only three hours exposure to this humidity

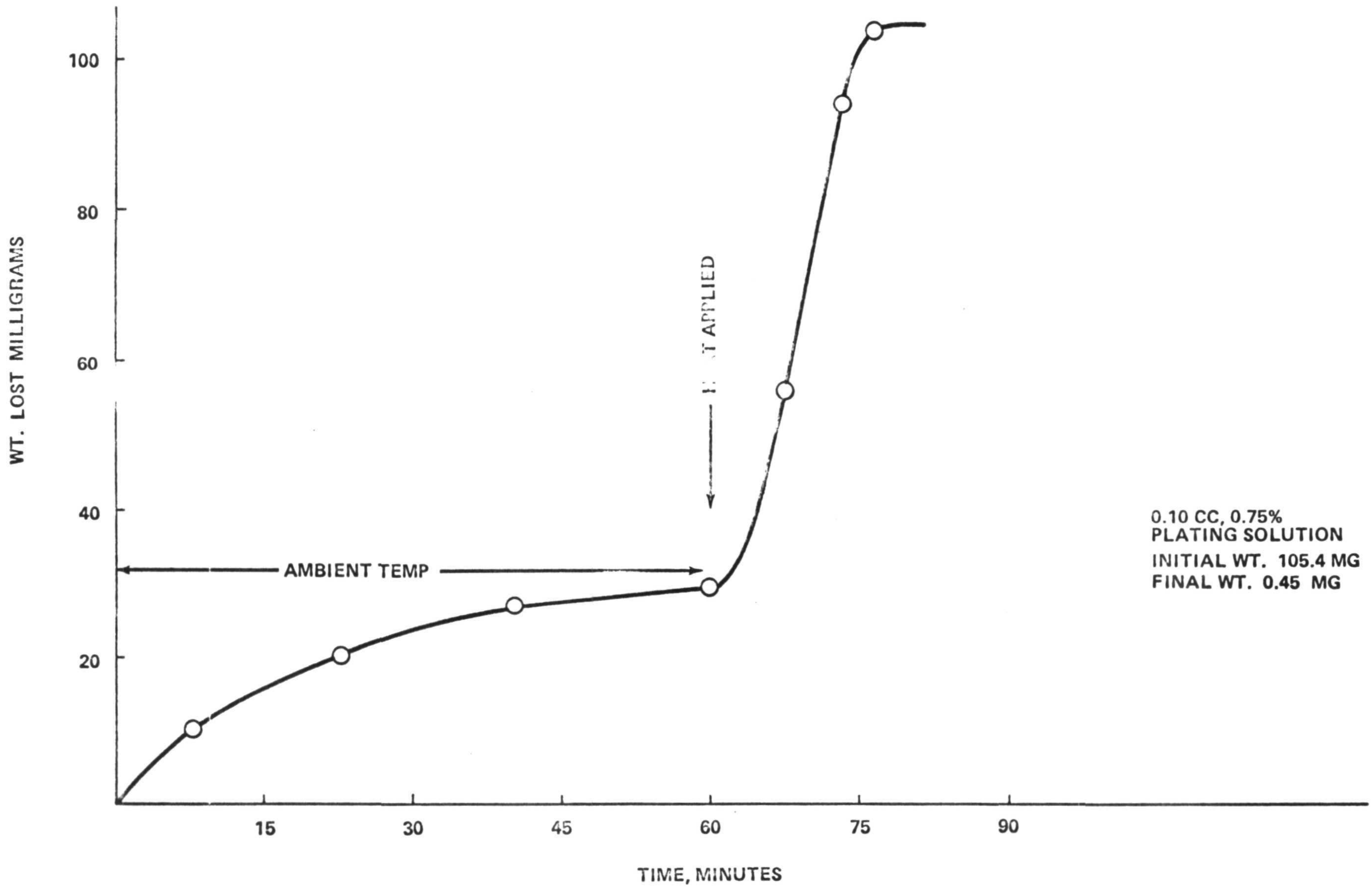


Figure 47. Loss Of H_2O From Plating Solution

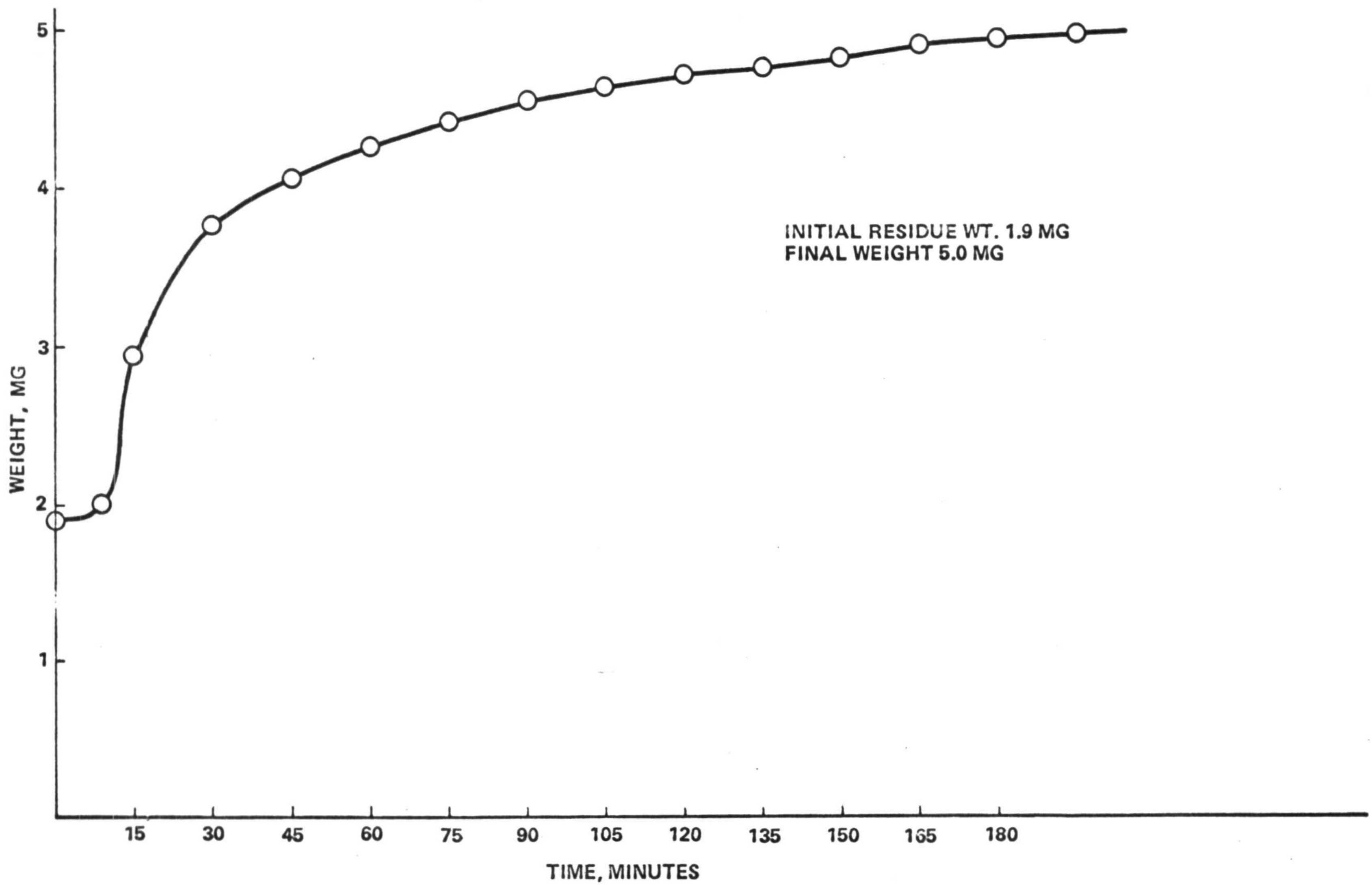


Figure 48. Weight Gain of Dried Plating Solution Residue Exposed To 100% Relative Humidity

environment. This definitely indicates that, even though the Vamistor Corporation is drying the resistors in a vacuum oven, subsequent exposure to the moist (45 to 65 percent relative humidity) plant air after drying (prior to sealing) provides ample moisture required for the electrochemical process that causes damage to the film and the subsequent change in resistance.

4. Effects of Temperature and Voltage. Since an electrochemical reaction should be dependent on both temperature and applied voltage, tests were conducted to determine the effect of each of these variables, with the other held constant. For these tests, production Vamistor resistors were selected from a group that had drifted. The resistors selected had drifted from 1.4 to 2.5 percent total in 167 hours of previous tests.

a. Drift Rate Versus Temperature At Constant Voltage. Four resistors were selected for this test, electrical leads were attached, and the resistors (along with a thermocouple) were sealed in a glass vial filled with a silicone fluid (DC-705). The vial was immersed in a circulating, constant temperature bath. The temperature was reduced to 13 degrees F with no voltage applied and the resistance of each of the four resistors were measured. Voltage was then applied (20 percent VR) and, at intervals, the resistance was again measured. The voltage was removed when moving to a higher temperature and was only re-applied after the resistor temperature had stabilized. A plot of resistance change per hour, as a function of temperature, is shown in figure 49. There is some scatter in the data, but all four resistors exhibit a double peak. A maximum change occurred between 20 and 30 degrees F, and a second smaller peak occurred at about 80 degrees F. The electrochemical reaction, discussed previously in this report, would be expected to be less at lower temperatures because of the inhibition of the reaction; however, the maximum rate of resistance change is encountered below the freezing point of water. Freezing point determinations of representative concentrations of plating solution indicate no substantial depression on the freezing point by the plating solution. No comprehensive explanation for the apparent low temperature resistance change maxima has been deduced at this time; however, several comments concerning this temperature related behavior are given below:

(1) It is difficult to assess the basic shape of the curve because of the many variables involved. It would be expected that the electrochemical reaction would be directly dependent on temperature. At some point below 32 degrees F, it is probable that the contained moisture freezes. This would not stop the reaction, since a solid electrolyte still permits current flow, but the degree of change should be at least an order of magnitude lower due to lowered carrier mobility.

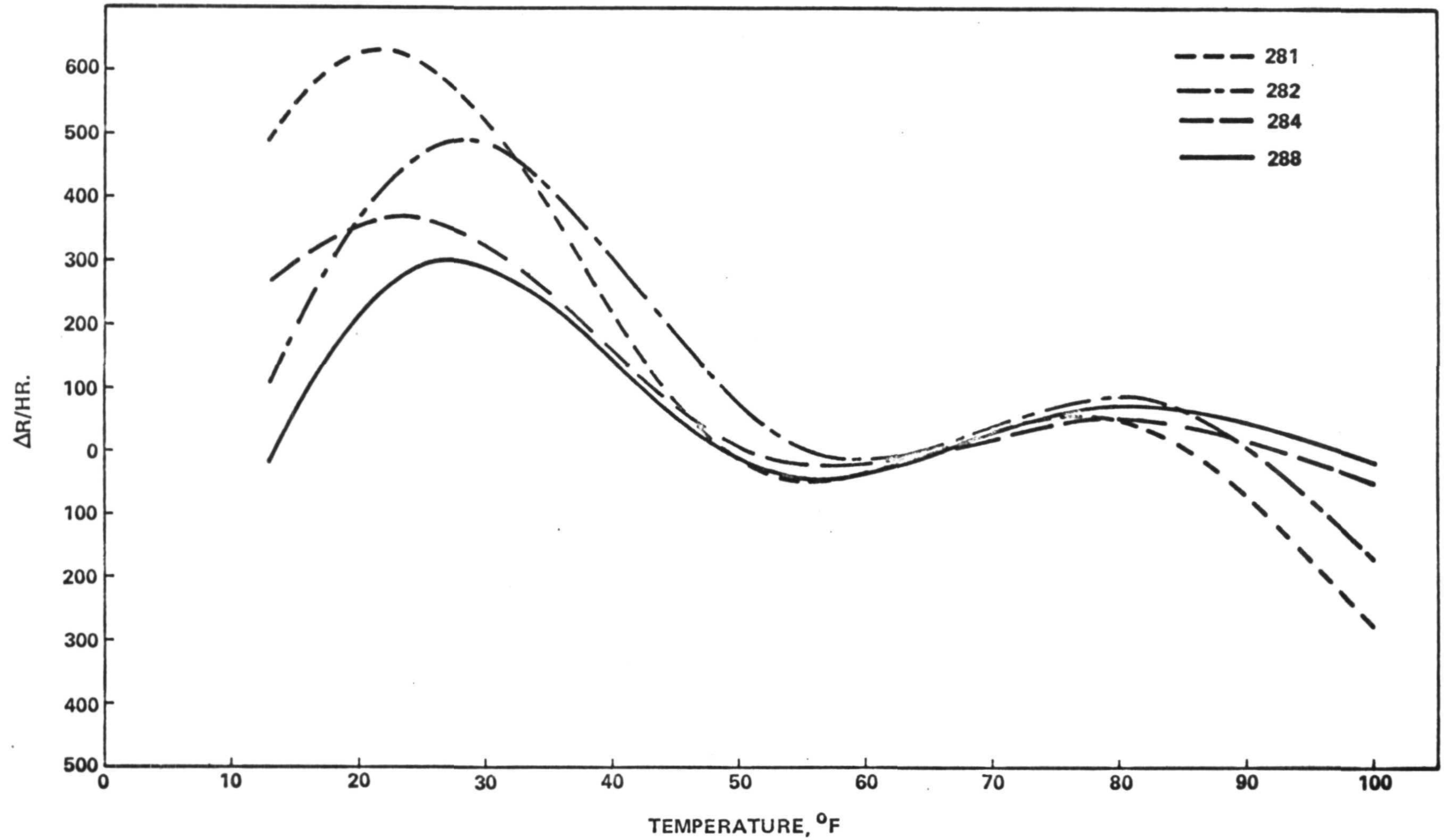


Figure 49. ΔR/HR. Versus Temperature at Constant Voltage (Initial Resistance ~ 565 K Ω)

(2) At (or near) the dew point, several effects should be present. It could be postulated that the region of maximum activity should be just below the dew point since the water vapor should be condensed out in liquid form; and conversely, minimum activity should be produced just above the dew point, based on the same reasoning. The situation is further complicated by the fact that the resistor represents a closed volume and changing the temperature from 10 to 100 degrees F would cause a pressure change within the resistor volume of from 13.0 psi to 15.0 psi. Further tests are being made to explain this temperature effect on drift rate. These tests and the results therefrom, will be given in the final report.

5. Electrical Parameter Studies. A series of tests were conducted on Vamistors that were injected with plating solution, dried, placed in a 100 percent relative humidity environment, and then subjected to an applied voltage. These tests were designed to yield information on the relative damage in production Vamistors caused by different types of applied voltage under known plating solution residue and humidity condition.

a. dc Tests. Six resistors (value 5K ohms nominal) were selected, holes were drilled in each endcap and a one percent plating solution was injected. The resistors were dried and placed in a chamber with a 100 percent relative humidity environment. A potential of 5 vdc was applied (22 percent VR) and the test was run for 425 hours. The results are given in figure 50. Because resistor R22 exhibited a 100 percent change in the first 8 hours, it was removed from test; therefore, the data for this resistor are not shown in figure 50. Resistor R28 exceeded 6 percent change at approximately 20 hours and was removed from test. The other four resistors averaged 1.4 percent total change over the test period.

The two resistors that were removed were sectioned and examined. Both exhibited the characteristic damage mechanism of Vamistor resistors that had drifted. Photomicrographs of these two resistors are shown in figures 51 and 52.

b. ac Tests (60 Hz). Two 41 K, six 5 K, one 20 K and one 3.5 K ohm resistors were selected for this test. The 20 K, the 3.5 K, and three of the 5 K ohm resistors were drilled and injected with plating solution. Two of the 5 K ohm resistors were not drilled, but were used as controls. These resistors were tested by Quality Laboratory and classified as non-leakers (good). The remaining 41 K ohm resistor, which had already drifted 1.8 percent, was also not drilled. All of the resistors were placed in a test chamber with 100 percent relative humidity and with 6 vac, 60 Hz applied. Dropping resistors were connected in series with the test resistors to hold the voltage drop across them to 10 percent VR.

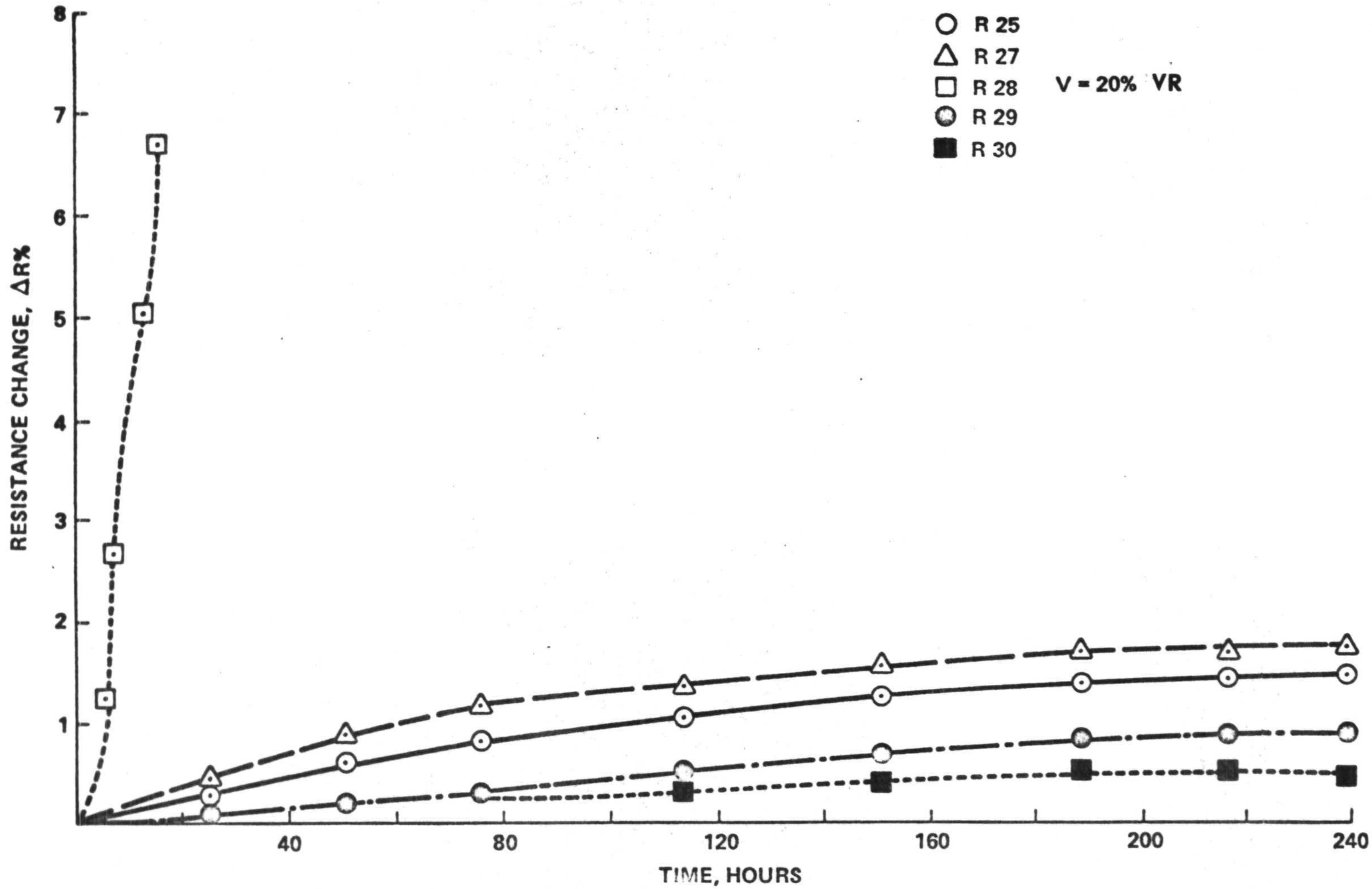


Figure 50. Effects of dc Voltage, Dried Plating Solution and 100% Relative Humidity On ΔR

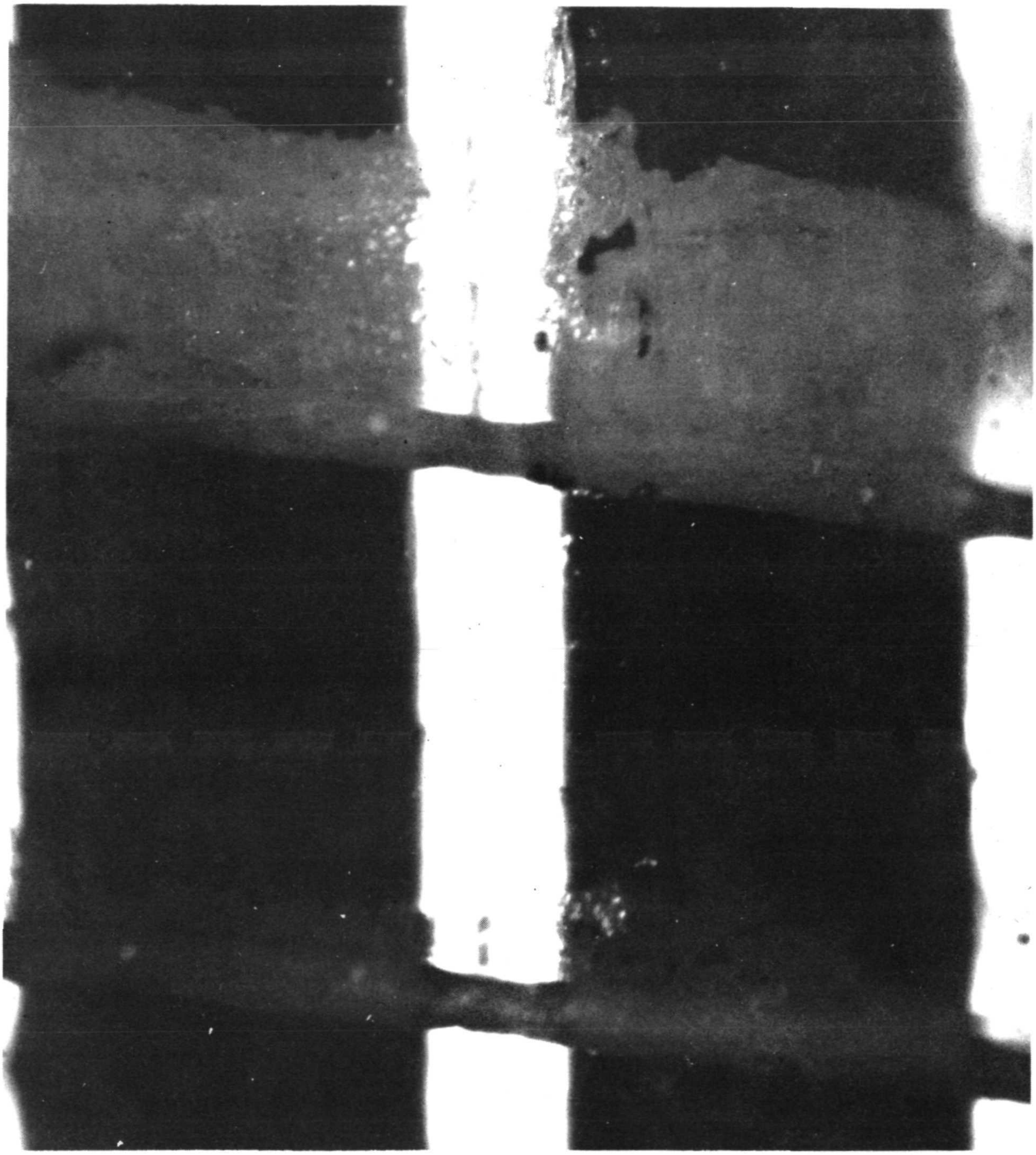


Figure 51. Resistor R22, Dried Plating Solution in 100% Relative Humidity At 22% VR For 8 Hours (100% Change)

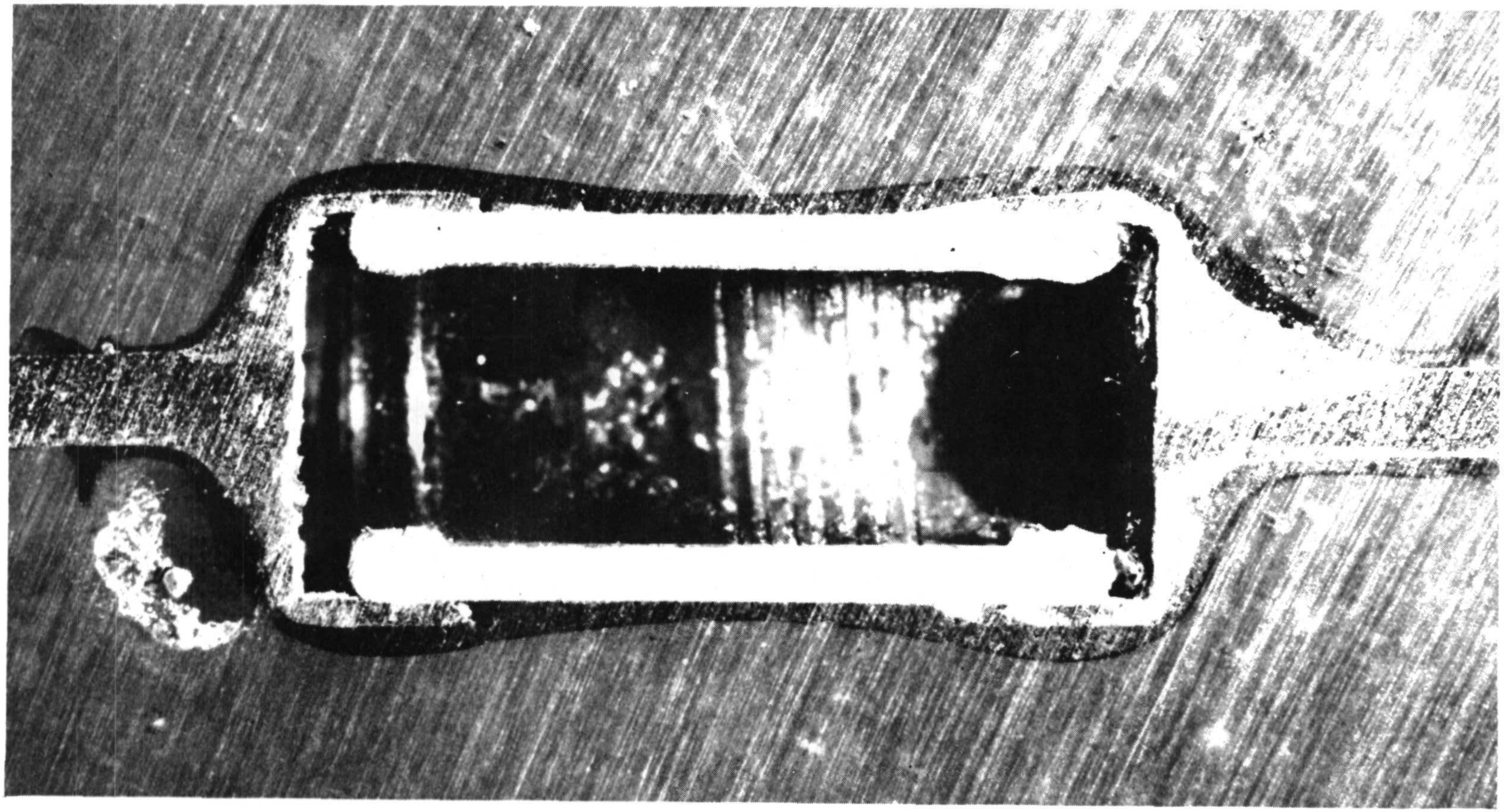


Figure 52. Resistor R28, Dried Plating Solution in 100% Relative Humidity At 22% VR For 138 Hours (20% Change)

The test matrix is shown in table 4.

Table 4. ac Test Matrix

RESISTOR	108	113	109	117	107	105	116	115	110	106
VALUE	20K	41K	5K	5K	5K	5K	5K	5K	41K	3.5K
STATUS*	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
HOLES	2	2	2	No	None	2	2	2	None	2
PLATING SOLUTION	Yes	No	Yes	No	No	No	Yes	Yes	No	Yes
HUMIDITY	Yes	Yes	Yes	No	No	Yes	Yes	Yes	No	Yes

*Good - Non-drifter as determined by Test
Bad - Drift more than 0.2% in 12 hours

At 74 hours, the voltage was increased to 12 vac, 60Hz, and at 85 hours R115 was removed for sectioning. At 89 hours, all external dropping resistors were removed. This produced an applied voltage in terms of percentage of VR as given in table 5.

Table 5. ac Applied Voltage

RESISTOR	108	113	109	117	107	105	116	115	110	106
% VR	26	20	56	56	56	56	56	56	20	66
Value (ohms)	20K	41K	5K	5K	5K	5K	5K	5K	41K	3.5K

This test was run for 431 hours, and the data are plotted in figures 53 and 54. A summary of these two plots is shown in table 6.

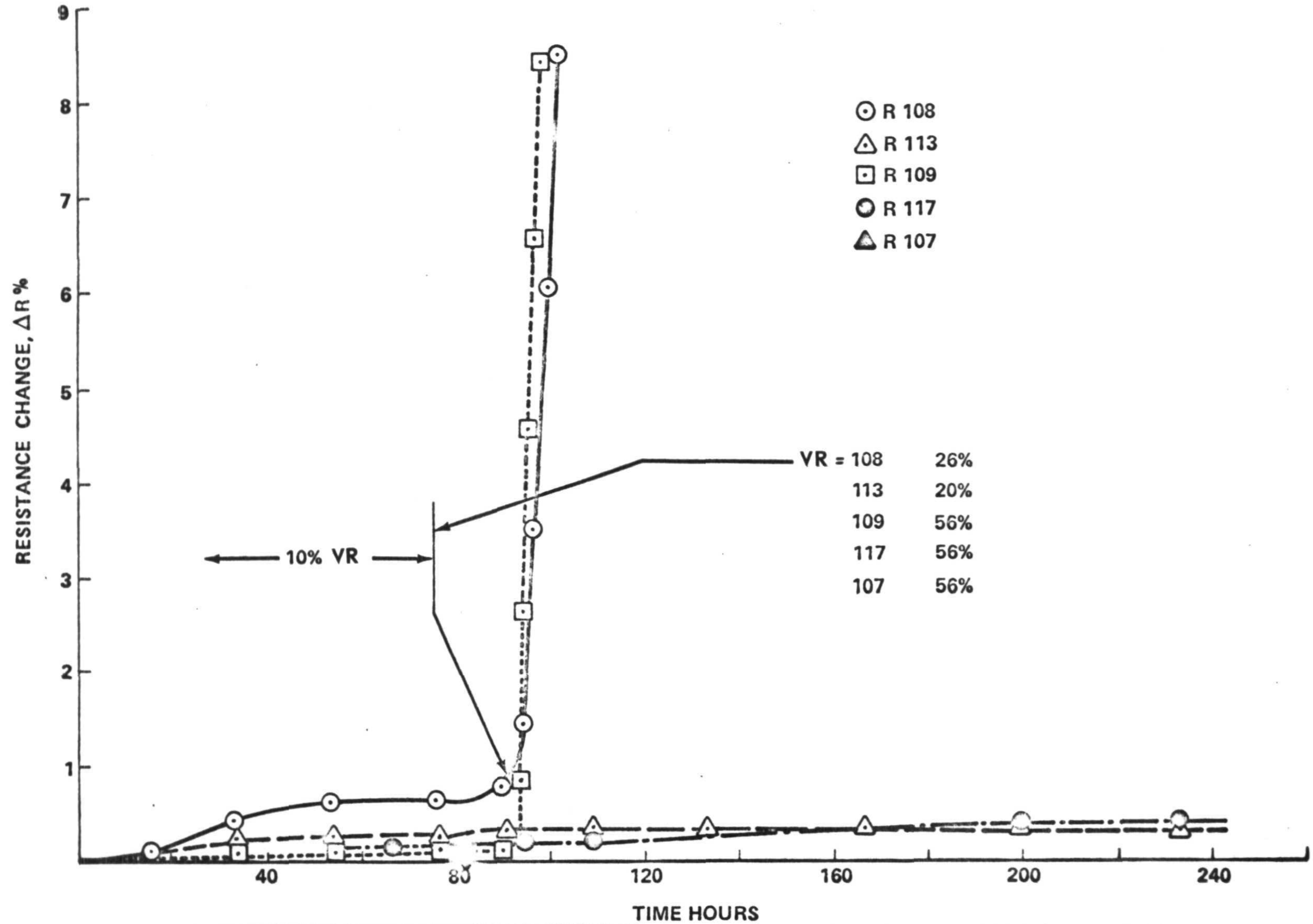


Figure 53. Effects Of 60 Hz, Dried Plating Solution, And 100% Relative Humidity On ΔR (Group I)

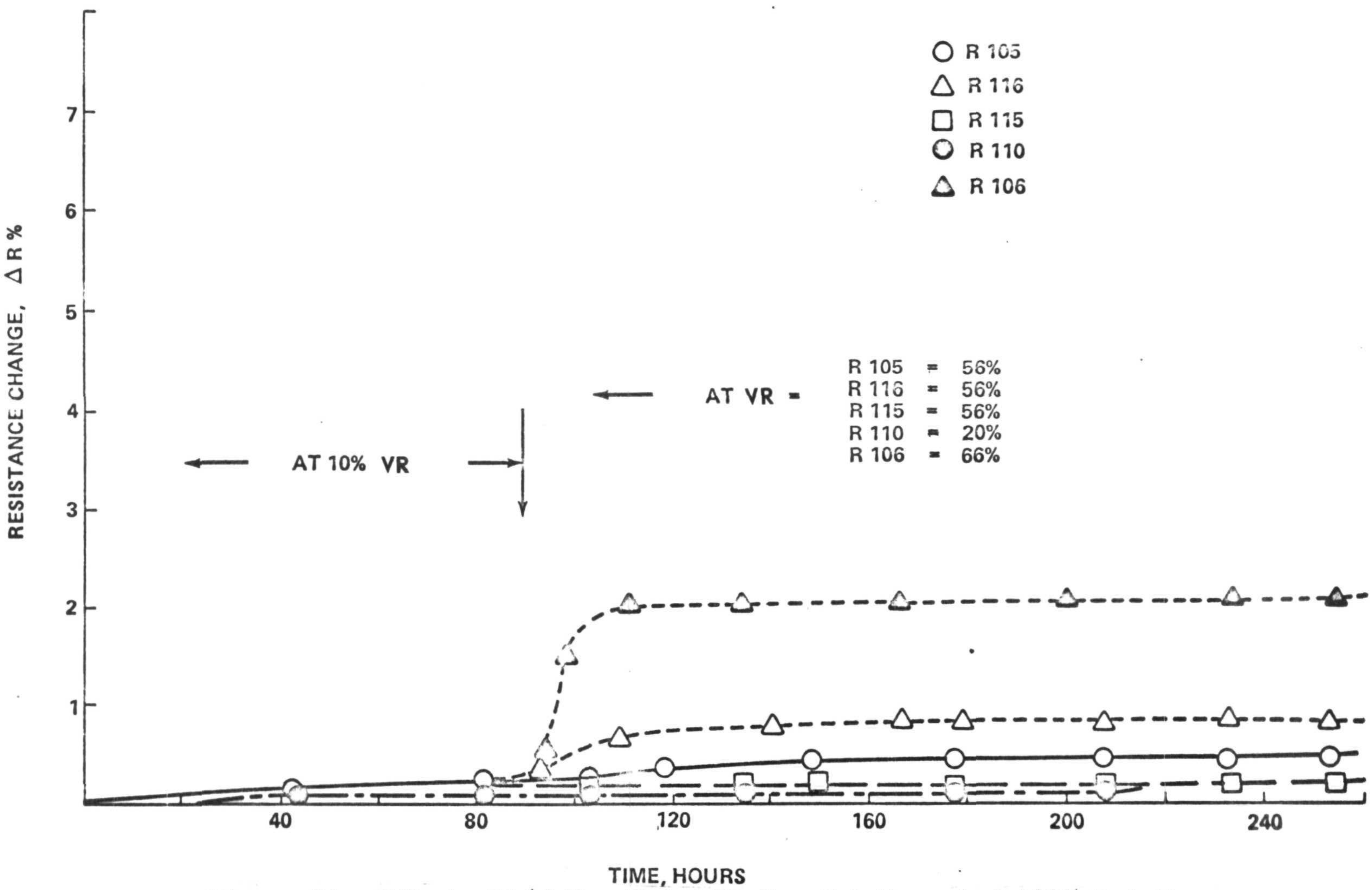


Figure 54. Effects Of 60 Hz, Dried Plating Solution, And 100% Relative Humidity On ΔR (Group II)

Table 6. ac Test Summary

RESISTOR	108	113	109	117	107	105	116	115	110	106
VALUE	20K	41K	5K	5K	5K	5K	5K	5K	41K	3.5K
%VR	26	20	56	56	56	56	56	56	20	66
PLATING SOLUTION	Yes	No	Yes	No	No	No	Yes	Yes	No	Yes
HUMIDITY	Yes	Yes	Yes	No	No	Yes	Yes	Yes	No	Yes
TOTAL % Change	*33.4	0.06	*44.4	0.48	0.46	0.57	0.80	*0.14	0.14	*28.5

*Reading when removed from test, R108 at 118 hrs., R109 at 118 hrs., R115 at 89 hrs., and R106 at 118 hrs.

All resistors which had plating solution and were exposed to humidity increased substantially in resistance, with the exception of R116 which increased only 0.8 percent. None of the resistors that were exposed to humidity only showed any substantial increase. The three resistors that were tested as received showed no appreciable change.

This test illustrates conclusively that 60 Hz ac produces damage in the resistor and that it appears to be quite voltage sensitive as shown in table 7. Table 7 compares operation at the lower voltage for 50 hours and at a higher voltage for the indicated times.

A summary of only those resistors injected with plating solution and exposed to humidity is given in table 8. Figure 55 shows R109 after 56 hours at 56 percent VR.

c. ac Tests (400 Hz). Nine 5.7 K and six 6.5 K ohm Vamistor resistors were selected for test. All were drilled and injected with one percent plating solution, dried, and placed in a chamber with a 100 percent relative humidity environment. The test was run for 66 hours with 5 vac (22 percent VR), 400 Hz applied. Only five of the resistors exhibited drift and these are plotted in figure 56. The drift rate varied from a low of 0.09 percent to a high of 0.614 percent. While those values are less than for 60 Hz, they still show that a Vamistor resistor can drift in 400 Hz service as indicated by the 400 Hz tests on the simulated resistors.

d. Pulsating dc tests. Three 5.5 K, three 6.5 K, and one 16.8 K ohm Vamistor resistors were selected for test. Three of the resistors were drilled, injected with a 0.75 percent plating solution, and dried (one each 17.8 K, 6.5 K and 5.5 K ohm). The other four resistors were tested as

Table 7. Effect of Voltage Level

RESISTOR	108	113	109	117	107	105	116	115	110	106
VR At 50 hrs	10	10	10	10	10	10	10	10	10	10
% Change	0.63	0.15	0.13	0.10	0.02	0.11	0.04	0.07	0.03	0.05
VR / At hrs.	26/118	20/380	56/118	56/380	56/380	56/380	56/380		20/380	66/118
% Change	33/4	0.06	44.4	0.48	0.46	0.57	0.8		0.14	28.5

Table 8. Resistance Change due to ac Voltage Level

RESISTOR	108	109	116	106
PERCENT RESISTANCE CHANGE/HR AT 10% VR	0.012	0.0026	0.0008	0.001
PERCENT RESISTANCE CHANGE/HR AT % VR	0.28/26	0.37/56	0.0021/56	0.24/66

received (controls). All resistors were placed in a test chamber with a 100 percent relative humidity environment and a pulsating dc voltage was applied. The voltage was 7 volts with a 400 microsecond pulse width and a 2,000 pulse/sec repetition rate. The test was run for 476 hours. The 16.8 K ohm resistor had increased by 2.14 percent, and the 5.5 ohm resistor had increased by 441 percent at the end of one hour and were removed from the test. The 6.5 K ohm resistor remained on test for the full 476 hours and at the end of the test had increased by 6.14 percent. None of the four control resistors had shown any change. Pulsating dc voltage appears to be almost as damaging as straight dc under the same environmental conditions. Figure 57 shows R923, which changed by 441 percent after 1 hour on pulsating dc.

e. Voltage Gradient Considerations. During the above tests some of the test resistors were sectioned and it was observed that there was considerable variability in the internal configuration. This was further pursued and it was determined from the vendor that this variability in number of helical turns, conductor width, groove width, etc., was due to the different resistor blanks used to obtain the various resistor sizes. Table 9 shows the range of blank values used in making the different sizes of one-eighth-watt Vamistor resistors. The most interesting feature of these data is that, within a given resistor size, there can be a different number of turns, conductor width, percentage of spiral cut, and groove width. If the voltage gradient is calculated by dividing the applied voltage by the product of the number of turns and the groove width, it can be seen that this can vary widely within some of the resistor sizes and from one size to another. Also, in general, as the resistor size increases, so does the voltage gradient. In order to determine the effect of voltage gradient on resistor drift, a test was made in which three non-hermetically sealed 511 K ohm Vamistor resistors were drilled, filled with 0.1 percent plating solution, dried, and exposed to 100 percent relative humidity environment.

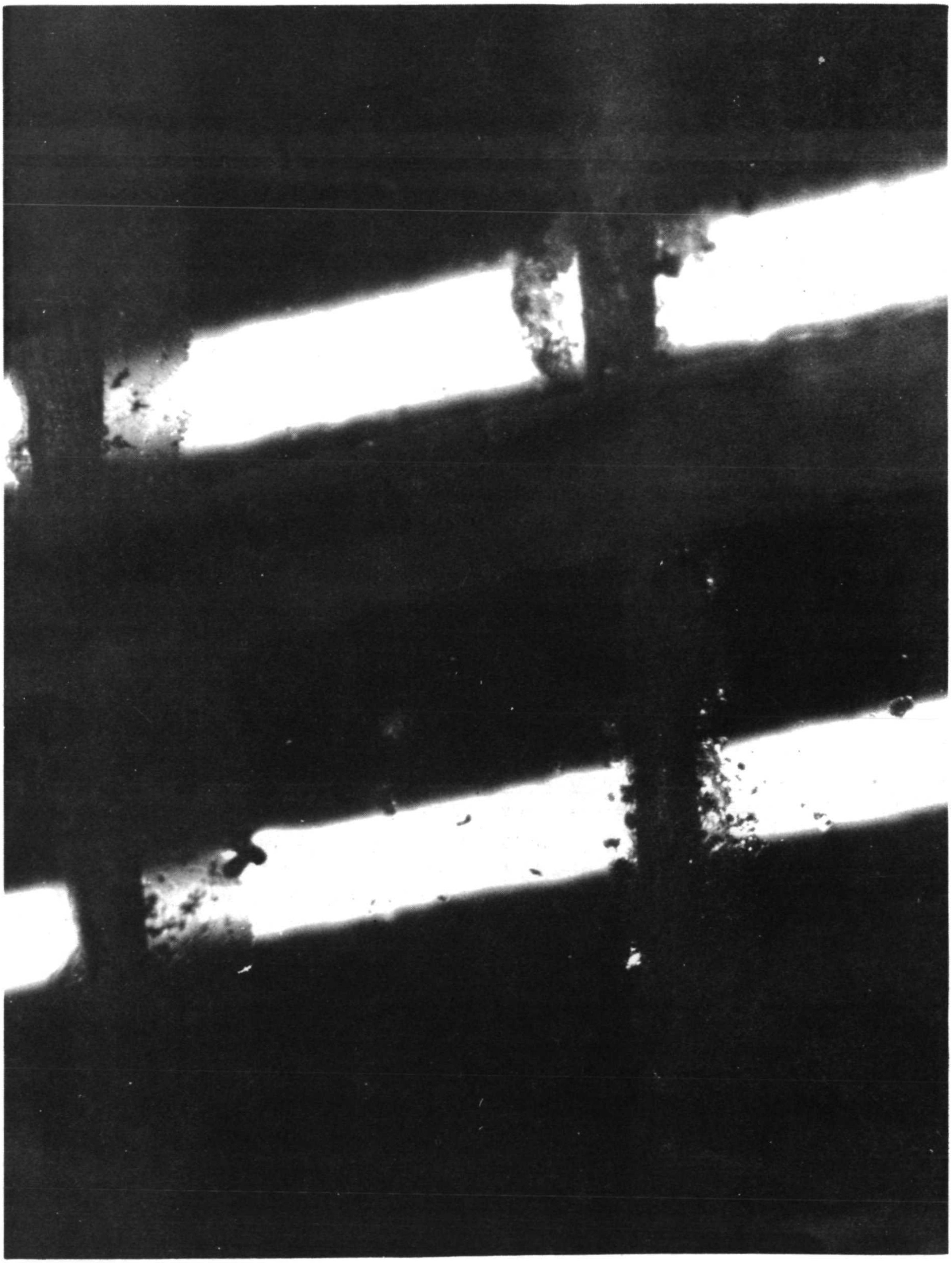


Figure 55. Vamistor Resistor Injected with 1% Plating Solution Dried, Run for 56 hours in 100% Relative Humidity at 56% VR, 60 Hz ac

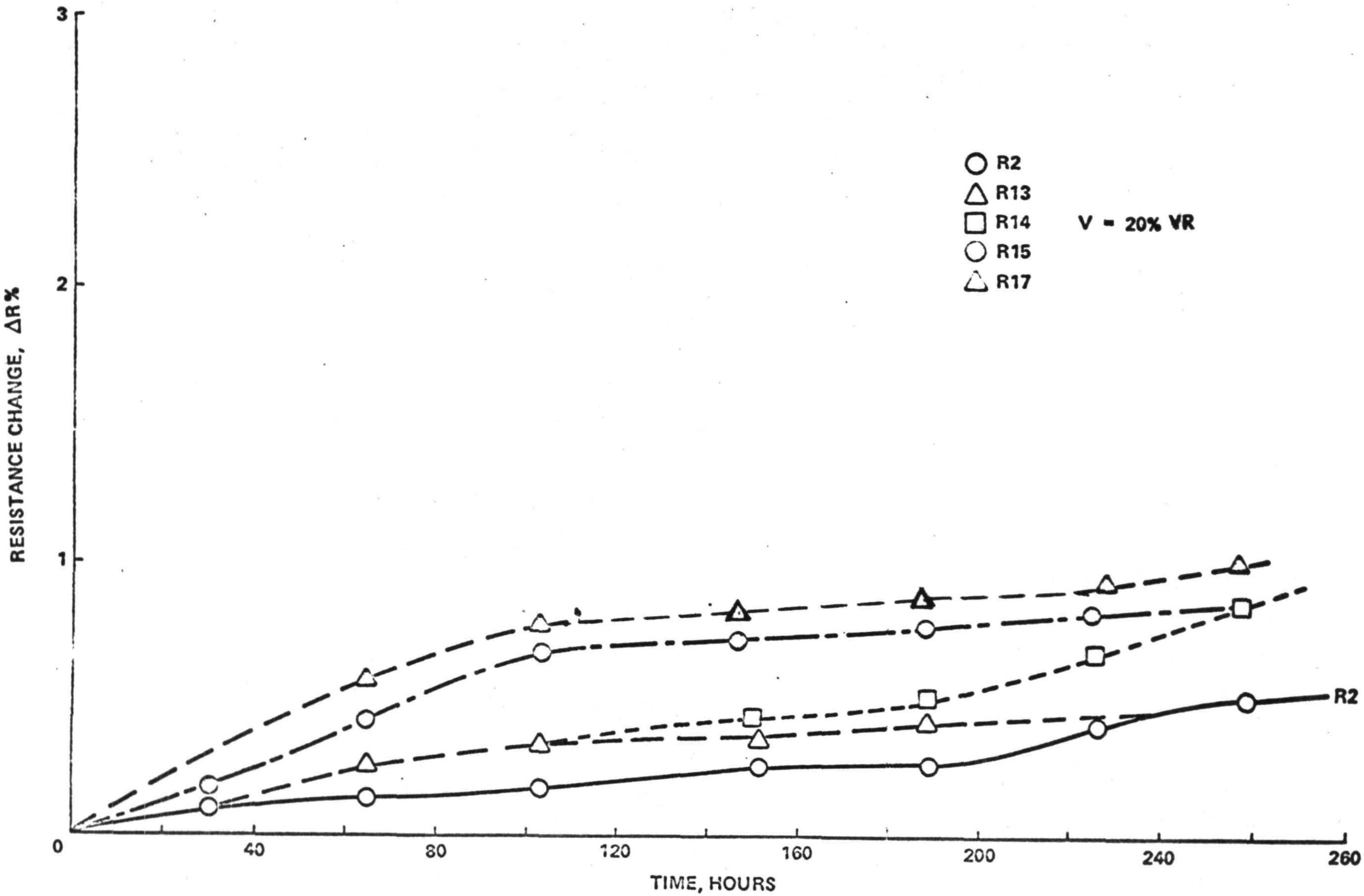


Figure 56. Effects Of 400 Hz, Dried Plating Solution, And 100% Relative Humidity On ΔR.

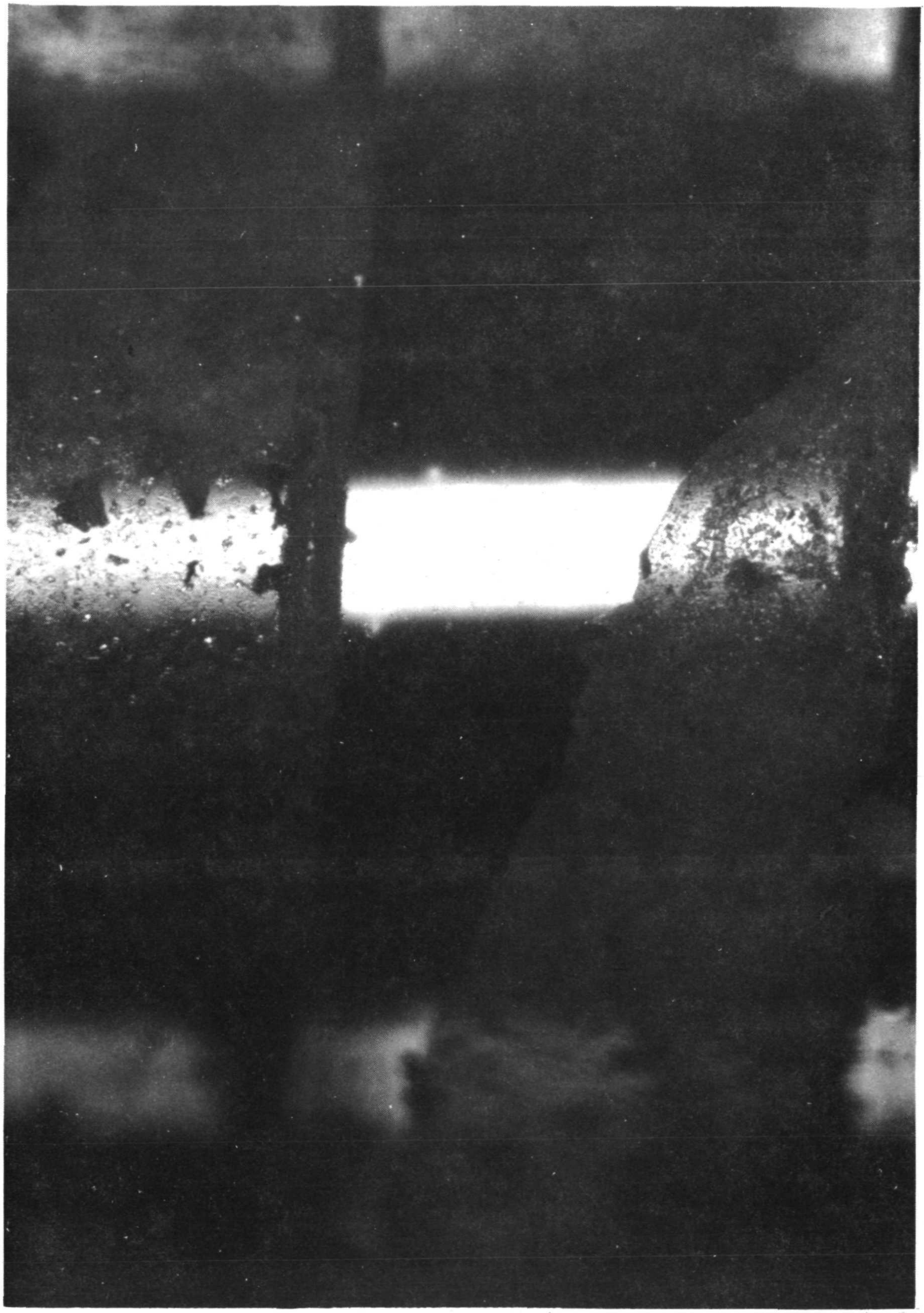


Figure 57. Resistor 923 0.75% Plating Solution Injected, Dried, Run at 100% Relative Humidity, on Pulsating dc for 1 hour. Total Change, 441%

Table 9. Internal Configuration Data On One-Eighth-Watt Vamistor Resistors

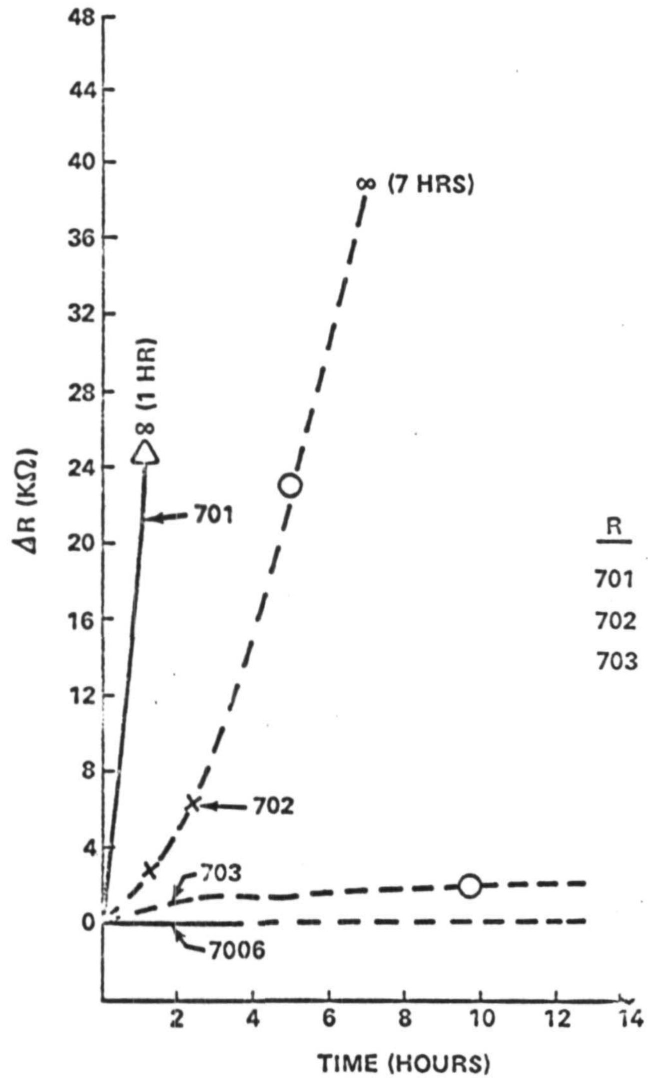
Resistor Value	Blank Value	% Spiral Cut	Number Turns (T)	Groove Width (G)	Connector Width (CW)	VR	0.2 VR	Volts (V_g) MIL @ 2 VR	$\frac{V_g}{CW}$
1K	21-26	80	7	0.004	0.025	11.2	2.2	0.08	0.0032
	185-200	70	2	0.007	0.066			0.16	0.002424
20K	45-50	100	21	0.003	0.009	50	10	0.16	0.0178
	400-425	75	8	0.002	0.022			0.63	0.0286
50K	85-92	70	18	0.003	0.006	79	16	0.30	0.050
	500-525	77	11.2	0.003	0.015			0.48	0.032
100K	92-100	85	25.5	0.004	0.004	112	22.4	0.22	0.055
	525-550	77	13.5	0.002	0.011			0.83	0.0755
300K	215-230	76	25	0.004	0.004	194-39		0.39	0.0975
	550-575	94	27	0.002	0.006			0.72	0.120
500K	260-275	60	24	0.003	0.003	250	50	0.70	0.233
	575-600	77	23	0.003	0.005			0.72	0.144

The applied voltage was 72 vdc (20 percent VR). A fourth resistor was tested as a control (no plating solution added). The results of this test are shown in figure 58. As can be seen, there was a vast difference in the drift (resistance change) of these supposedly "identical" resistors tested under the same conditions. The resistors were then sectioned and the internal configuration of each was analyzed. The data obtained are also given in figure 58. As can be seen, voltage gradient (Vg) does not correlate to resistance change but when the voltage gradient is divided by the conductor width (CW), correlation with the drift data results. This is not surprising since, if the voltage gradient (driving force for the electrochemical process) is the same, the percentage change in resistance will be proportional to the width of the conductor. If the conductor width is small a larger change will occur, in the same time period, than if it is larger. Figure 59 is a plot of Vg/CW versus resistance value for one-eighth watt Vamistor resistors. It can be seen that, as the resistor value increase, so does Vg/CW. It is important to note that the 500 K ohm resistors can have by far the largest value of Vg/CW; also, they have the smallest film thickness. Based on this, it would seem that these resistors would be more susceptible to the damage mechanism than the other resistor sizes, all other conditions being the same.

A comprehensive series of tests using both simulated and actual resistors are underway to obtain further data on the effect of Vg/CW and film thickness on drift rate at constant contamination and humidity levels. The results of these tests will be given in the final report.

SECTION VI. CONCLUSIONS

The study discussed in the preceding sections established that the Vamistor resistor drift/failure mechanism is an electrochemical process following, in many respects, the classical laws of electrolysis. The basic process involves an electrochemical cell setup in the resistor between a pair of nichrome turns, one serving as the anode and the other as the cathode. The spiral groove, where nichrome has been removed, represents the gap between the electrodes and the conducting medium or electrolyte is water with varying concentrations of the copper sulfate complex. The voltage applied across the resistor in operation provides the driving force for the process. The critical point, in the process that relates to failure mechanism, is the reduction in area of one or more of the nichrome turns by anodic dissolution. This causes an increase in resistance or drift. If particular conditions of voltage, as well as moisture and plating solution contamination, are present in the resistor the nichrome band (representing the anode) is completely consumed at one point and the resistor electrically opens.



INTERNAL CONFIGURATION DATA

R	GROOVE WIDTH	CONDUCTOR WIDTH	TURN	% WT	VOLT. GRAD. Vg	$\frac{V_g}{cw}$
701	3	5	32.5	60	0.74	.15
702	3	7	29	–	0.83	.12
703	3	6	38	70	0.63	.105

Figure 58. Voltage Gradient Versus ΔR Tests On 511 K Resistors

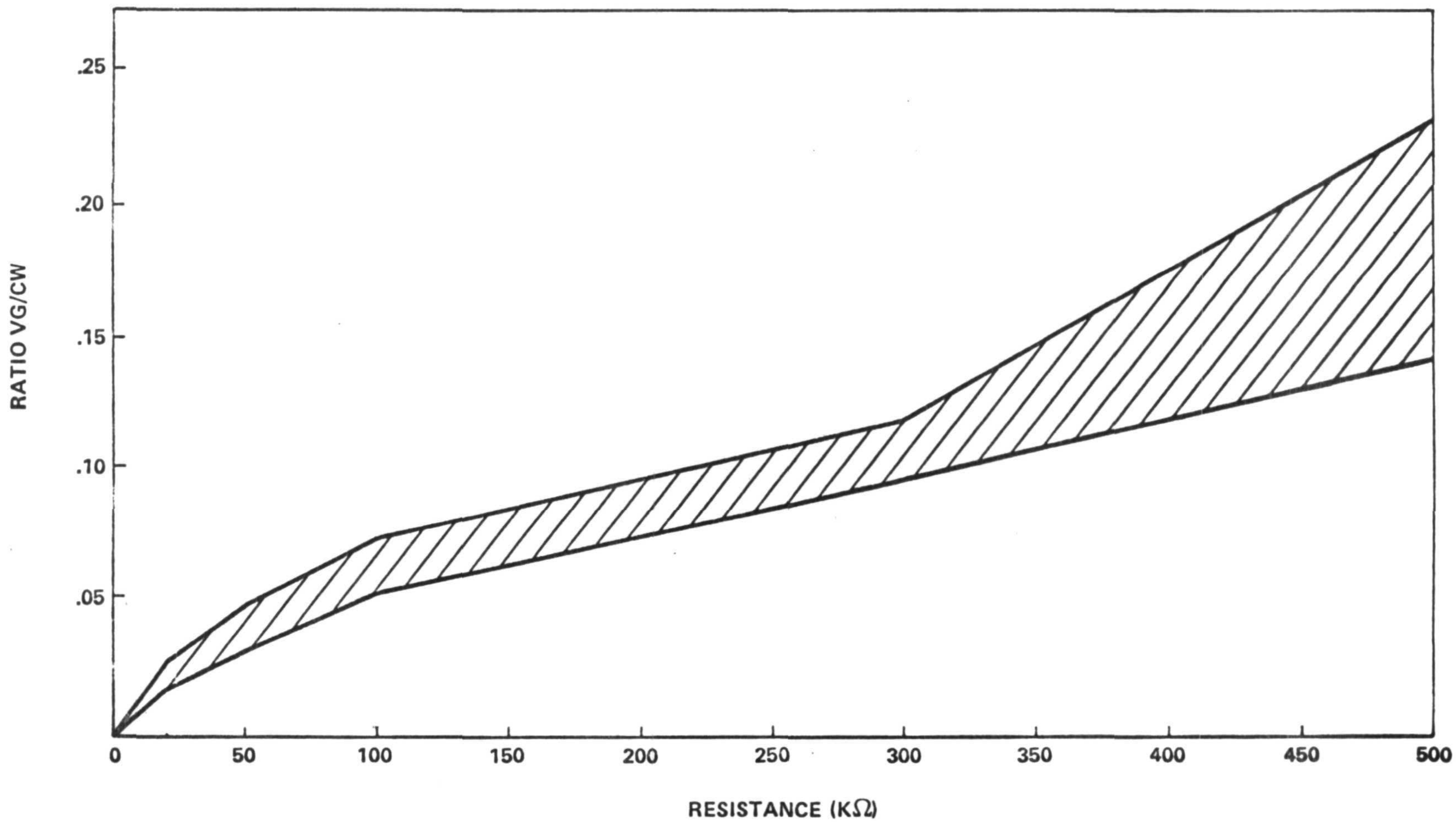


Figure 59. Resistor Value Versus Ratio Voltage Gradient/Conductor Width For One-Eighth-Watt Vamistor Resistors

The relative insensitivity of the resistors to drift at low voltages (< 10 percent VR) is consistent with the presence of a decomposition potential for the electrolyte, below which the electrochemical process is very slow.

On the basis of the electrolytic cell studies this voltage is in the range of 1.5 to 1.7 volts, and it appears to be insensitive to electrolyte concentration or electrode separation over a wide range. Once the decomposition potential has been exceeded, the cell current for a given voltage increases appreciably with higher plating concentrations and decreasing electrode separation.

The dramatic decrease in resistance changes in the cell, through the voltage range of the decomposition potential, is again emphasized by the time-to-failure studies. In the area of 1.5 to 2.0 volts, the time required for the cell to electrically open by complete anode dissolution dropped exponentially; however, the 1.25 vdc cell has been operating for 1000 hours continuously with no significant anode dissolution.

The stabilization of the drifting resistors (or tendency toward lower drift rates) is believed to be a complex function of water depletion (by electrolysis), with attendant variations in decomposition potential resulting from initial confining pressures inside the resistor, and of the change in the nichrome band width as a function of the electrochemical action.

As this study progressed, the problems attending an unambiguous, quantitative explanation of each phenomenon of the resistor drift process have become more fully appreciated. The number of interdependent variables that influence the propensity of each resistor to drift and the subsequent combinations and permutations of these variables are staggering when one attempts an analytically satisfying definition of the drift mechanism.

These parameters are summarized below:

- Moisture content in resistors.
- Quantity and concentration of plating solution.
- Distribution of plating solution within resistor.
- Varying chemical composition of electrolyte within resistor.
- Varying batch size and varying exposure to rinse solution concentration.

- Various voltage gradients within the same resistor size.
- Conductor width and thickness.
- Sealed versus leaking resistor bodies.

Finally, when the operational variables of voltage, temperature, and time are added it is not surprising that some unexplainable anomalies were observed in the test data.

In summary, it is believed that the test data proves conclusively that the mechanism which produces the increased resistance in the Vamistor resistor is a reduction in the cross sectional area of the deposited NiCr conductor, caused by an electrochemical reaction. The electrochemical reaction results from a residue from the copper plating solution (introduced during the manufacturing process), entrapped water vapor (also introduced during the manufacturing process), and the normal voltage applied to the resistor. All three factors are required to initiate damage to the conducting film.

It has also been shown that the manufacturer's process can produce sufficient deposit of the plating solution and that this plating solution will absorb moisture of a sufficient quantity to activate the electrochemical process.

The test data also indicates that the drift rate is a function of temperature, in a manner which is yet unexplained and which is still under investigation.

In general, the quantity of change is dependent on the type of applied voltage; and damage is noted for dc, pulsating dc, 60 Hz ac and 400 Hz ac.

ADDENDUM I

To Appendix A

PRODUCTION OF SIMULATED THIN FILM RESISTORS

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ADDENDUM I

PRODUCTION OF SIMULATED THIN FILM RESISTORS

a. Masks. Vapor deposition masks were prepared from 0.003-inch monel by photo etching the desired pattern. The pattern consisted of 0.020-inch spacings, with 0.0325-inch conductor strips on a 1-inch by 3-inch slide, with a 0.25-inch conductive border. This pattern gave an effective conductor length of approximately 32.5-inches.

b. Substrate Preparation. Pyrex and Corning 2947 glass substrates, one inch by three inches, were cleaned by washing with Joy detergent, rinsing twice in distilled water with a final rinse in ethyl alcohol, and dried with a heat gun. The ceramic substrates, Steatite L-5, were coated with the Vamistor formulated glaze and fired by the Non-Metallics Branch. These slides were then forwarded, for vapor deposition, without any additional surface preparation.

c. Vapor Deposition. Vapor deposition was performed with the substrate in the vertical position to keep any foreign material from settling on the coated surface. Vapor deposition could not be done upward to mask geometry. The substrate holder contained six slides with three masks, each mask covering two slides. The vacuum chamber was evacuated to 10^{-6} torr in 30 minutes and the substrates heated to 300 degrees C, using four quartz lamps, prior to deposition. The filaments were prepared by winding 2 1/2-inches of number 22 nichrome or 7-inches of 0.021-inch Topet A wire over two, 3-inch tungstan wires. The nichrome was monofilar wound over 1 1/2-inches of the tungsten. Joule heating of the filament assembly was used to obtain vaporization temperature.

Deposition time for nichrome ranged from 0.5 to 1.75 minutes and yielded a resistance range of 15K to 45K ohms. Film thickness ranged from 750 to 1500 angstrom. Thickness measurements were made by multiple beam interferometry on step slides which were produced during each deposition.

d. Aging. All slides were aged at 300 degrees C in air (circulating oven) for 24 hours to stabilize the deposited films.

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ADDENDUM II

To Appendix A
VAMISTOR PRODUCTION AND FAILURE RATE DATA

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ADDENDUM II

VAMISTOR PRODUCTION AND FAILURE RATE DATA

Vamistor production per week for the first two quarters of 1972 versus vendor-generated failure rate data is shown in figures II-1 and II-2. These data show no correlation between total production and the percent of failures of Vamistor resistors tested. For example, weeks 21 and 24 were high production weeks and the percent of failures was moderate; while weeks 10 and 22 were low to moderate production weeks and the percent of failures was high. For many weeks, few resistors were available for test; therefore, the failure data given are probably not accurate for these dates. Data for the last two quarters of 1972 are not complete and will be presented in the final report.

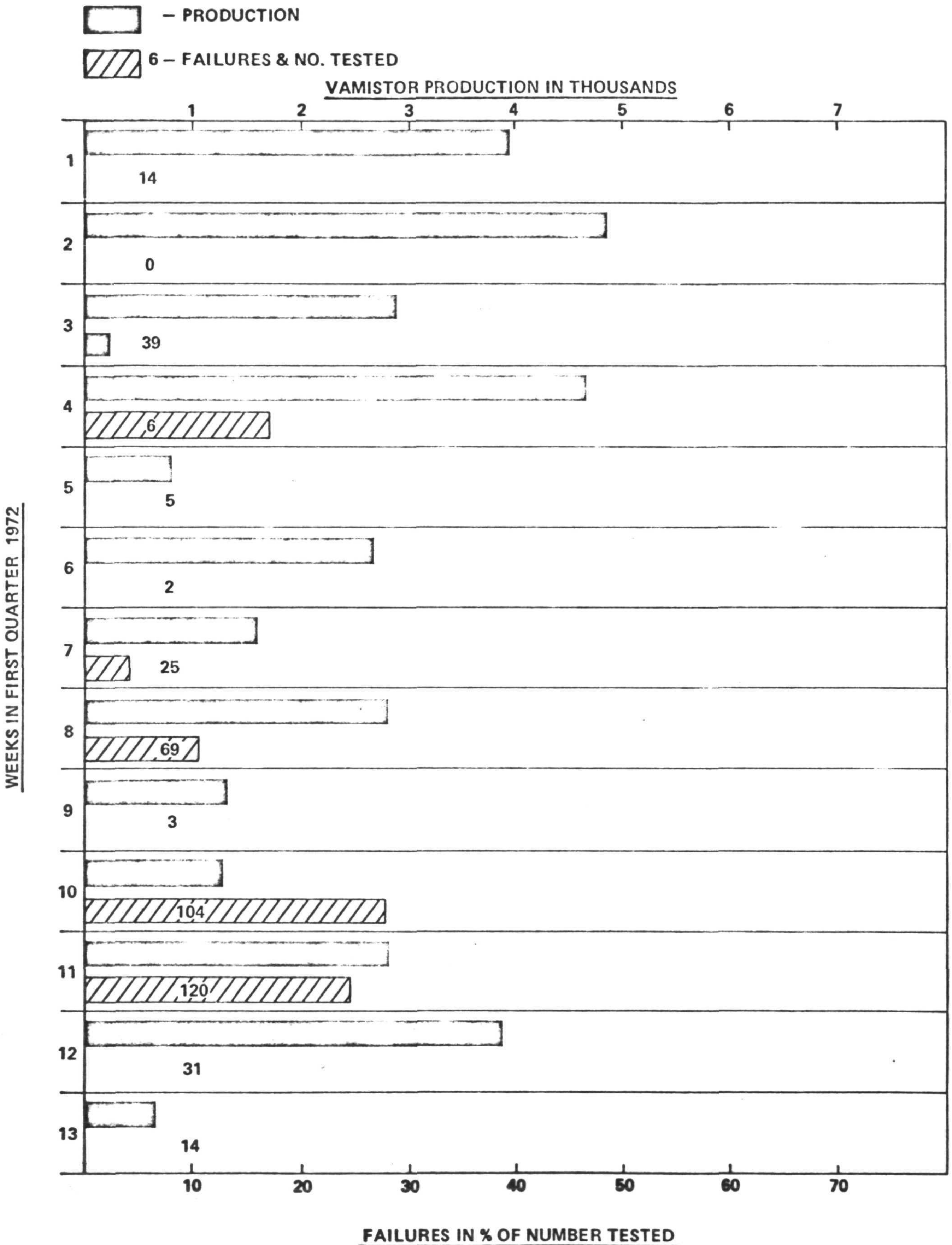

Figure II-1. Vamistor Production And Failure Rate For First Quarter 1972

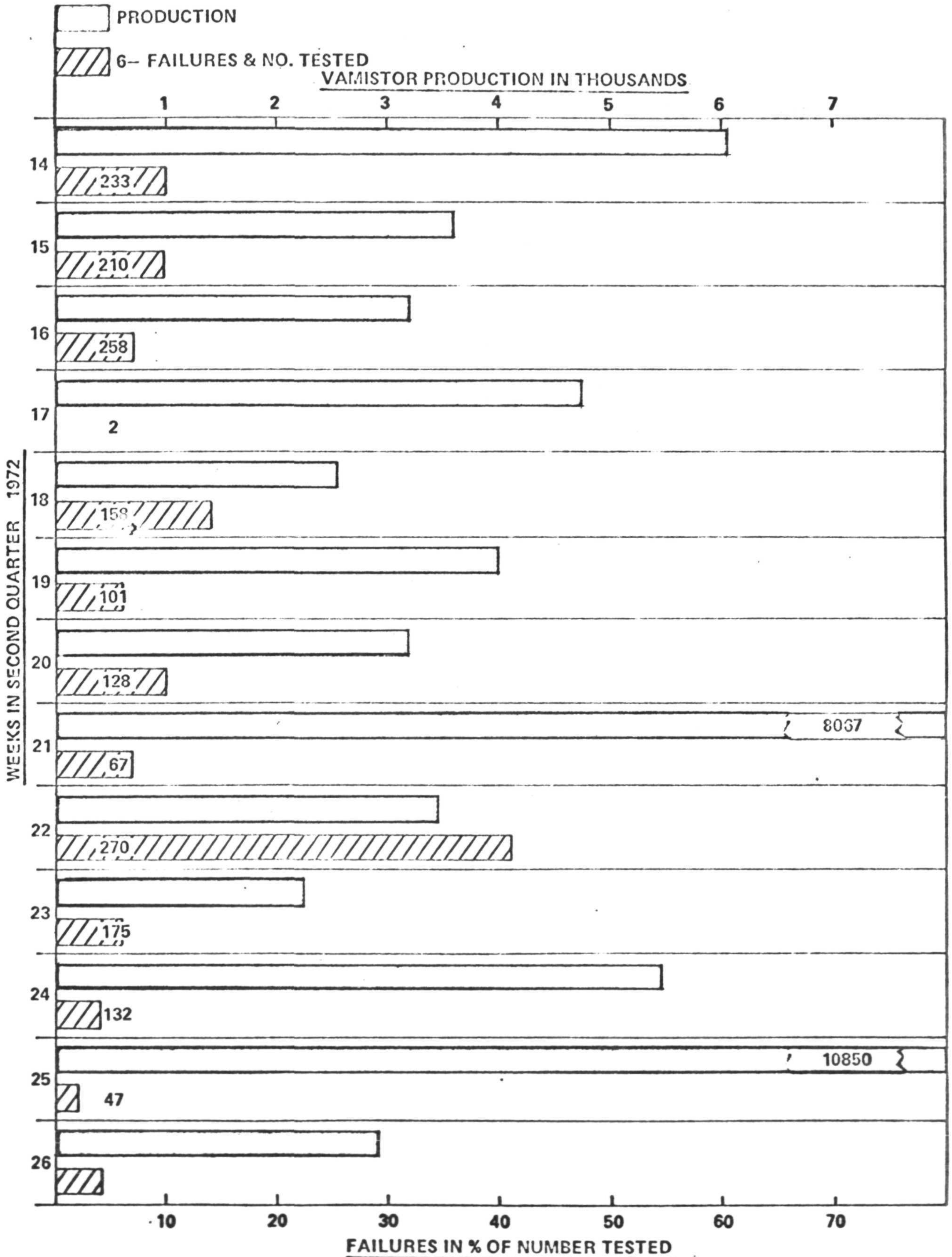

Figure II-2. Vamistor Production And Failure Rate For Second Quarter 1972

APPENDIX B

ALERTS GSFC-72-10 AND F8-A-72-01

(PLEASE TYPE ALL INFORMATION - SEE INSTRUCTIONS ON REVERSE)

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

ALERT

(Reporting Parts and Materials Problems)

1. GENERIC CLASSIFICATION
Resistor, Fixed Film

2. ALERT NO.
GSFC 72-10

3. DATE

DAY	MO.	YEAR
28	9	72

4. MANUFACTURER AND ADDRESS
Vamistor Division of
Wagner Electric Corp.
Cedar Knolls, NJ

5. PROCUREMENT SPECIFICATION
MIL-R-55182

6. REFERENCE
--

7. MANUFACTURER'S DESIGNATION
RNR/RNC 55, RNR/RNC 60

8. LOT/DATE CODE OR SERIAL NO.
Prior to 7226

9. SPECIAL REQUIREMENTS OR ENVIRONMENT *(Requirements placed on or extreme environment to which item was exposed.)*
None

10. PROBLEM SITUATION AND CAUSE *(State facts of problem and cause – failure mode and mechanism – project and function)*

A spacecraft contractor detected unstable resistors during pre-flight testing of flight equipment. The resistance of some Vamistor units increased as much as 50% after approximately 200 hours of operation at low power levels. Tests on other Vamistor resistors revealed that with 20-30% of rated voltage applied at room temperature, defective units exhibited an approximate linear increase of resistance during 300 hours of operation.

Analysis of the failed units revealed evidence of metal migration of the resistive film due to the presence of contaminants. All of the subject parts had previously

(Continued on Page 2)

11. ACTIONS TAKEN *(State all actions taken to correct the problem situation.)*

a. An additional burn-in of all subject parts in stock was performed by the contractor. This was done at 20-30% of rated voltage (.2 to .3E $=\sqrt{PR}$) for 50 hours at room temperature using a reject criterion of % $\Delta R \geq 0.2\%$. Resistors in the flight equipment were replaced with units burned-in to the above schedule. Tests by the manufacturer have demonstrated that this failure mechanism can be detected in 12 hours using a reject criterion of % $\Delta R \geq 0.05\%$. The 50 hour test yielded 9% defects from a total of 278 pieces of RNR 55 resistors from various lots and various resistance values.

b. As of date code 7226, the manufacturer has instituted revised process controls

(Continued on Page 2)

12. RECOMMENDATIONS FOR FURTHER ACTION *(Suggestions to prevent recurrence.)*

It is recommended that all RNR & RNC resistors made by Vamistor prior to the 26th week of 1972 be subjected to a low voltage burn-in. Parts that are installed in equipment may be judged on the basis of a burn-in of samples from the same lots. (NOTE - In addition to the date code marking required by MIL-R-55182, a manufacturer's lot code number appears on each part. The lot code number should be used in determining the quality of a lot on a sampling basis.) As an additional precautionary measure, it is further recommended that samples from lots bearing date

(Continued on Page 2)

13. CONTACT POINTS FOR INFORMATION *(Name, affiliation, telephone)*

Leonard E. Buyer, Quality Assurance Division
NASA-Goddard Space Flight Center
Greenbelt, Maryland 20771
301-982-2437

14. MANUFACTURER NOTIFIED
H. Brandi

DAY	MO.	YEAR
20	9	72

15. ALERT COORDINATOR *(Name, affiliation)*
Orssell Dorrell
Chief, Quality Assurance Division

16. SIGNATURE OF ALERT COORDINATOR
Russell W. Dorrell 9/25/72

17. GENERIC CLASSIFICATION
Resistor, Fixed Film

18. ALERT NO.
GSFC 72-10

19. GIDEP INDEX NO.
651.55.H6-A-72-10

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10. PROBLEM SITUATION AND CAUSE (Continued)

passed the Group A acceptance tests of MIL-R-55182 which includes a short time (one hour) overload. This overload test is ineffective in detecting the metal migration failure mechanism. The migration occurs when a polarizing voltage is applied over an extended period of time and occurs more rapidly when there is insufficient energy dissipated in the resistor to heat the metal film and vaporize moisture off the film. The resistors are constructed with the metal film on the inside surface of a tubular ceramic substrate and this cavity is hermetically sealed. Investigation by the manufacturer has shown that contaminants (including moisture) were sealed in the defective units during fabrication.

11. ACTIONS TAKEN (Continued)

to insure the removal of contaminants before sealing. Commencing with the effective date, random lots of C&E characteristic RNR/RNC style resistors from each days production are being sampled for conformance with the $\leq 0.05\%$ change in resistance limit after a low voltage burn-in of 12 hours.

12. RECOMMENDATIONS FOR FURTHER ACTION (Continued)

codes after 7226 be subjected to a low voltage burn-in test until the effectiveness of the manufacturer's corrective measures and lot controls can be determined.

MSFC COMMENTS ON RECOMMENDATIONS FOR FURTHER ACTION

Action recommended in the last sentence has been accomplished and corrective actions found acceptable by the ALERT originator.

(PLEASE TYPE ALL INFORMATION - SEE INSTRUCTIONS ON REVERSE)

GOVERNMENT-INDUSTRY DATA EXCHANGE PROGRAM

ALERT

(Reporting Parts and Materials Problems)

1. GENERIC CLASSIFICATION

RESISTOR, METAL FILM, PRECISION

17 NOV 1972

2. ALERT NO. F8-A-72-01

3. DATE

DAY	MO.	YEAR
11	9	72

4. MANUFACTURER AND ADDRESS

Wagner Electric Corp.
Vamistor Division
Cedar Knolls, N. J. 07927

5. PROCUREMENT SPECIFICATION

MIL-R-55182

6. REFERENCE This ALERT same as GSFC-72-10

7. MANUFACTURER'S DESIGNATION

RNR55C1332FP

8. LOT/DATE CODE OR SERIAL NO.

7110C

9. SPECIAL REQUIREMENTS OR ENVIRONMENT *(Requirements placed on or extreme environment to which item was exposed.)*

N/A

10. PROBLEM SITUATION AND CAUSE *(State facts of problem and cause – failure mode and mechanism – project and function)*

An RNR55C1332FP resistor increased in value by 50% after approximately 200 hours operation in the ERTS recorder, resulting in an equipment malfunction.

Also returned for failure analysis with the failed part was another unit which measured well above the nominal resistance of 13,300 ohms when retested by Engineering.

Analysis of these parts revealed the following:

1. The cause of the high positive change in resistance was due to the migration of the metal film resistance element which reduces the resistance path and correspondingly increases the resistance.

(See page 2)

11. ACTIONS TAKEN *(State all actions taken to correct the problem situation.)*

Problem was traced to several steps in the Vendor's cleaning operation. Process controls were tightened to eliminate the condition. A low voltage screen was invoked on 100% of the product after this process change. Results of this screen produced zero rejects.

12. RECOMMENDATIONS FOR FURTHER ACTION *(Suggestions to prevent recurrence.)*

Date Codes of RNR resistors manufactured by this Vendor prior to 7226 are suspect and should be submitted to low voltage screen by applying 20 to 30% of rated voltage for 50 to 70 hours at 25°C. Positive changes in excess of +0.20% should be rejected.

13. CONTACT POINTS FOR INFORMATION *(Name, affiliation, telephone)*

James Wilkes (609 - 963-8000, Ext. PC 5730)
RCA, Central Engineering, Camden, N. J.

14. MANUFACTURER NOTIFIED

DAY	MO.	YEAR
3	10	72

15. ALERT COORDINATOR *(Name, affiliation)*

C. Divor, RCA, Central Engineering

16. SIGNATURE OF ALERT COORDINATOR

C Divor

17. GENERIC CLASSIFICATION RESISTOR, METAL FILM, PRECISION

18. ALERT NO. F8-72-01

19. GIDEP INDEX NO. 651.55-F8-A-72-01

GIDEP Form 4:12-71
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ALERT NO.: F8-72-01

ITEM NO.: 10 (Continued)

2. This phenomena occurs if the resistive element becomes contaminated (with moisture for example) and the polarizing voltages are insufficient to heat the film.

3. High resistance values (5KΩ -10KΩ and up) will be more susceptable to this failure mechanism than low ranges (10-100 ohms).

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APPENDIX C

ALERTS MSFC-72-25 AND MSFC-72-25A

(PLEASE TYPE ALL INFORMATION - SEE INSTRUCTIONS ON REVERSE)

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

ALERT

(Reporting Parts and Materials Problems)

1. GENERIC CLASSIFICATION Resistor, Fixed Film	2. ALERT NO. MSFC-72-25	3. DATE 14 Dec. 1972 DAY MO YEAR
4. MANUFACTURER AND ADDRESS Vamistor Division of Wagner Electric Corp. Cedar Knolls, NJ	5. PROCUREMENT SPECIFICATION MIL-R-55182	6. REFERENCE GSFC 72-10 F8-A-72-01
	7. MANUFACTURER'S DESIGNATION RNR/RNC 55 RNR/RNC 60	8. LOT/DATE CODE OR SERIAL NO. A11

9. SPECIAL REQUIREMENTS OR ENVIRONMENT *(Requirements placed on or extreme environment to which item was exposed.)*

None

10. PROBLEM SITUATION AND CAUSE *(State facts of problem and cause — failure mode and mechanism — project and function)*

Refer to ALERT GSFC 72-10

11. ACTIONS TAKEN *(State all actions taken to correct the problem situation.)*

658 Vamistor resistors of 70 different part numbers (3K ohms to 200K ohms) and date coded 7012 through 7236 (30 different d/c) were tested to criteria specified in GSFC 72-10. After 12 hours burn-in at .2 to .3 rated voltage, 154 resistors (in 14 different d/c) did not meet 0.2% drift criteria established for test (i.e., resistance increased beyond limit). The drift of 57 of 110 resistors (d/c 7235) is significant due to the large sample involved. Data indicates that this problem is not dependent on date codes since the failed date codes include 7234, 7235, and 7236 (later than d/c 7226).

12. RECOMMENDATIONS FOR FURTHER ACTION *(Suggestions to prevent recurrence.)*

Identify all critical equipment using Vamistor resistors. Conduct thorough research for previous problems and failures that may be attributed to Vamistor resistors.

Report usage and previous problems to MSFC as rapidly as possible.

13. CONTACT POINTS FOR INFORMATION *(Name, affiliation, telephone)*

Federico Laracuente, S&E-QUAL-QT
George C. Marshall Space Flight Center 205/453-3987

14. MANUFACTURER NOTIFIED
11 Dec. 1972
DAY MO. YEAR

15. ALERT COORDINATOR *(Name, affiliation)*
Elizabeth G. Manning, S&E-QUAL-QRA
George C. Marshall Space Flight Center

16. SIGNATURE OF ALERT COORDINATOR
Elizabeth G. Manning

17. GENERIC CLASSIFICATION: Resistor, Fixed Film

18. ALERT NO. MSFC-72-25

19. GIDEP INDEX NO. 651.55.H1-A-72-01

NASA FORM 863 MARCH 1971 Previous Editions Are Obsolete.

(PLEASE TYPE ALL INFORMATION - SEE INSTRUCTIONS ON REVERSE)

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

ALERT

(Reporting Parts and Materials Problems)

1. GENERIC CLASSIFICATION	Resistor, Fixed Film	
2. ALERT NO.	MSFC-72-25A	
3. DATE	29 Jan 1973 (DAY / MO. / YEAR)	
4. MANUFACTURER AND ADDRESS	Vamistor Division of Wagner Electric Corp. Cedar Knolls, NJ	
5. PROCUREMENT SPECIFICATION	MIL-R-55182	
6. REFERENCE	GSFC 72-10, F8-A-72-01	
7. MANUFACTURER'S DESIGNATION	RNR/RNC 55 RNR/RNC 65 RNR/RNC 60 RNR/RNC 70	
8. LOT/DATE CODE OR SERIAL NO.	All	

9. SPECIAL REQUIREMENTS OR ENVIRONMENT *(Requirements placed on or extreme environment to which item was exposed.)*

None

10. PROBLEM SITUATION AND CAUSE *(State facts of problem and cause — failure mode and mechanism — project and function)*

Refer to GSFC-72-10 as stated on MSFC-72-25

11. ACTIONS TAKEN *(State all actions taken to correct the problem situation.)*

Extensive testing and analysis at MSFC has shown a large percentage (approx. 16%) of all Vamistor resistors in tested date codes 7012 through 7241 are susceptible to increased resistance drift above 0.2%. Resistors from 68 date codes in this time period have been tested. The failure mechanism is not restricted to particular date codes or resistance values. Usage at 15% to 70% of rated voltage, V_R(DC), is the highest risk area. Below 15% V_R(DC) the risk is significantly reduced. Above 70% V_R(DC), there is some risk; but at this voltage the resistors have a tendency to stabilize around 0.5% drift. (See Chart #1) After approximately 250 hours nearly all drifters had shown up. Drifters continue to drift up to approximately 250 hours, then the rate of increase of resistance tends to (Cont'd on page 2)

12. RECOMMENDATIONS FOR FURTHER ACTION *(Suggestions to prevent recurrence.)*

Since the Vamistor process may yield resistors in the above date codes contaminated by copper plating electrolyte and moisture and contaminated units are not screened out by the MIL-SPEC tests, it is recommended that circuit use of Vamistor resistors be analyzed. In instances where drift would be detrimental to circuit operation, replacement should be considered. Tests are continuing--interim report will be issued in late February and supplemented as necessary. Full details will be available in MSFC Technical Report to be published in March 1973.

13. CONTACT POINTS FOR INFORMATION *(Name, affiliation, telephone)*

Federico Laracuente, S&E-QUAL-QT
George C. Marshall Space Flight Center 205/453-3987

14. MANUFACTURER NOTIFIED

23 Jan 1973 (DAY / MO. / YEAR)

15. ALERT COORDINATOR *(Name, affiliation)*

Elizabeth G. Manning, S&E-QUAL-QRA
George C. Marshall Space Flight Center

16. SIGNATURE OF ALERT COORDINATOR

Elizabeth G. Manning

17. GENERIC CLASSIFICATION: Resistor, Fixed Film

18. ALERT NO.: MSFC-72-25A

19. GIDEP INDEX NO.: 651.55.H1-A-72-01

NASA FORM 863 MARCH 1971 Previous Editions Are Obsolete.

11. ACTIONS TAKEN (Cont'd)

slow down. Temperature does influence the drift, but in most hardware applications, it is not significant, since drifters occur at all but very extreme limits. A total of 4,380 parts have been subjected to various percents of rated voltage at various temperatures. Mean drift of the total population tested is approximately 0.9%; 3% show greater than 5.0% drift, 2% greater than 10% drift and 0.8% greater than 20% drift. Four opens have occurred in the test program. See attached charts for further information.

Analysis shows that drift is due to electro-chemical erosion of the nichrome film. For the mechanism to operate the following are required:

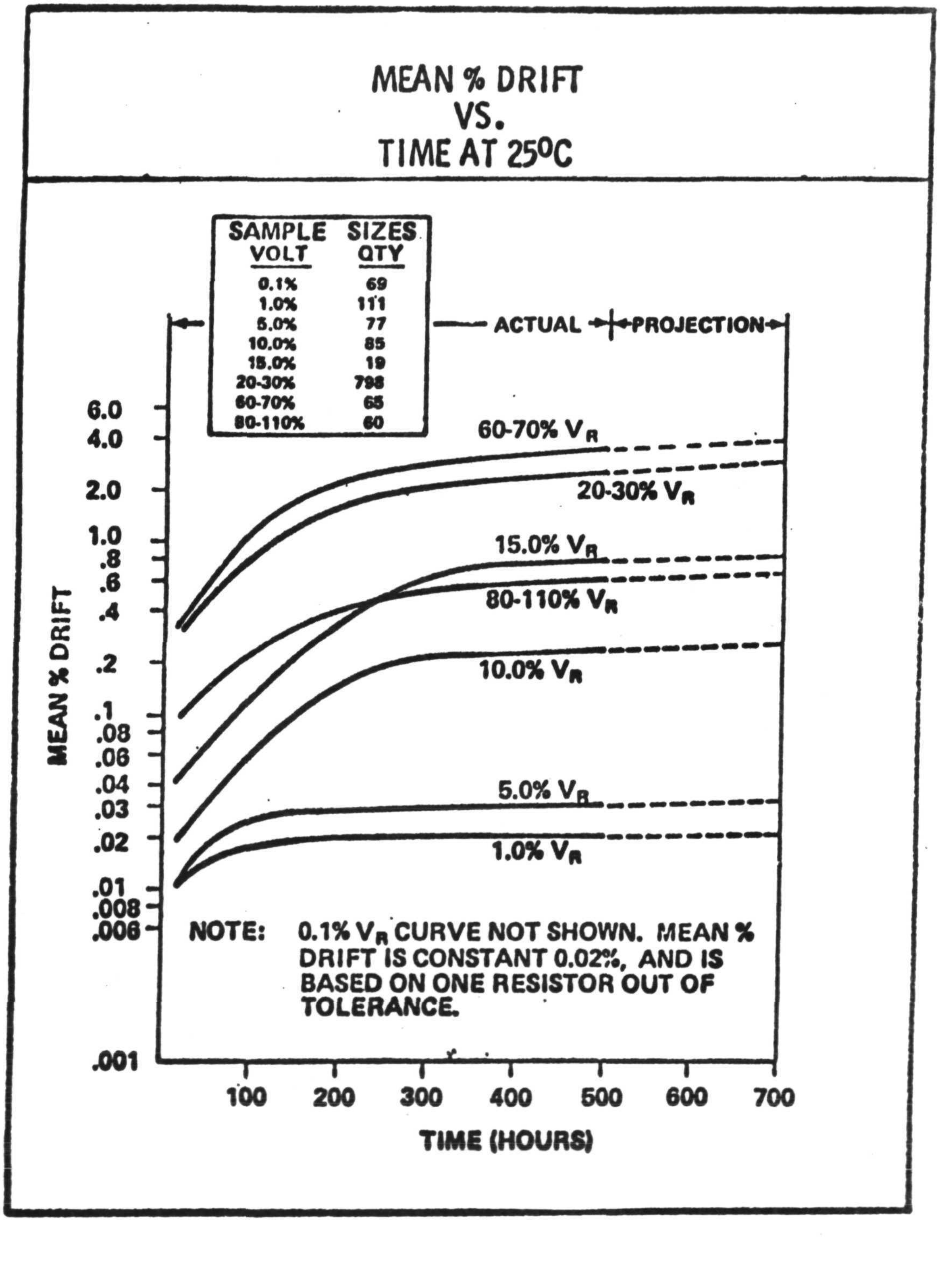
1. Plating solution residue on the film
2. Humidity inside the resistor
3. Voltage applied to the resistor
4. Period of time at voltage

The rate of drift is dependent on:

1. Quantity, distribution, and concentration of residue
2. Humidity level
3. Voltage type and magnitude

3

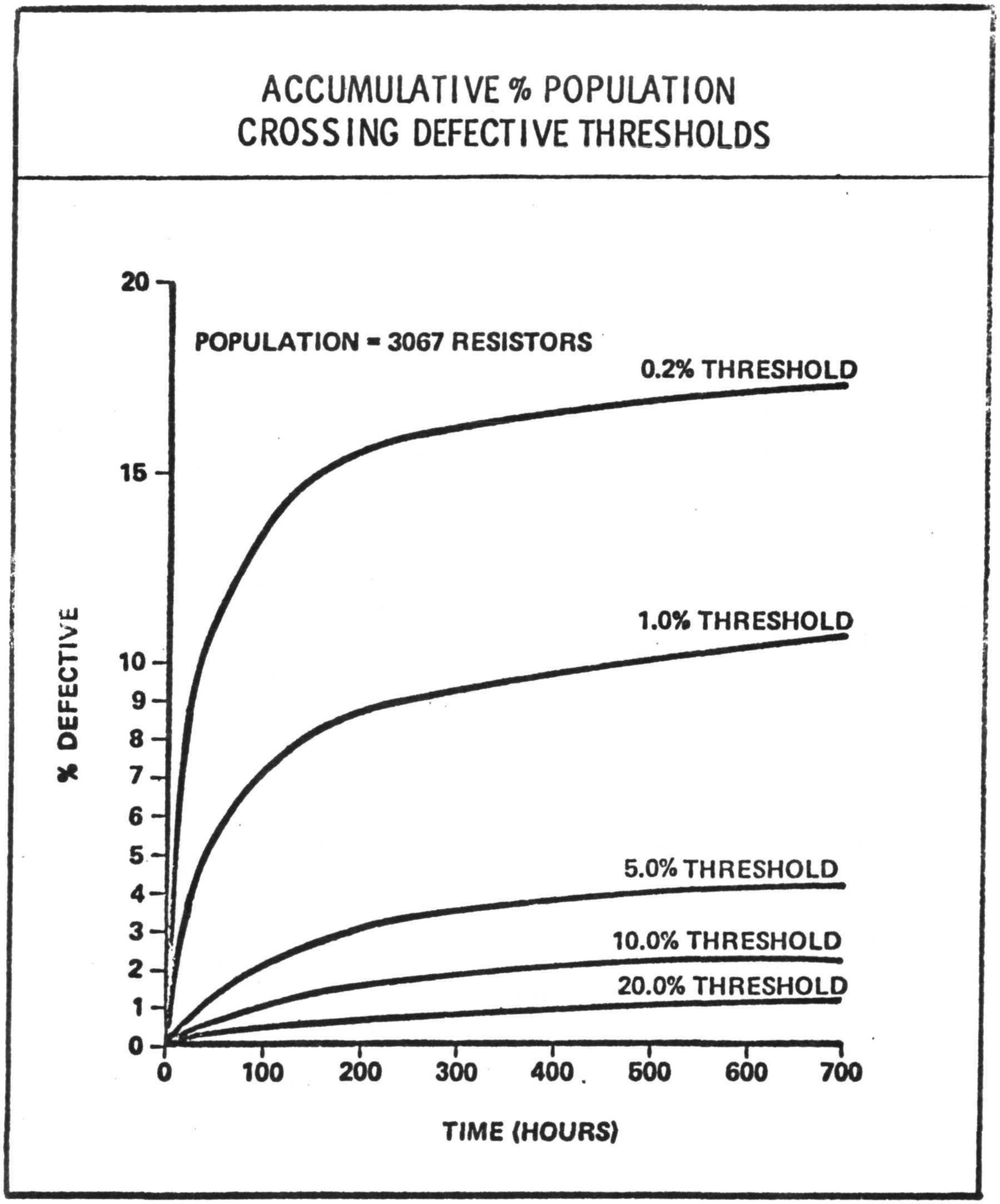
CHART 1



MEAN % DRIFT
VS.
TIME AT 25°C
SAMPLE SIZES
VOLT QTY
0.1% 69
1.0% 111
5.0% 77
10.0% 85
15.0% 19
20-30% 798
60-70% 65
80-110% 60
ACTUAL
PROJECTION
60-70% V_R
20-30% V_R
15.0% V_R
80-110% V_R
10.0% V_R
5.0% V_R
1.0% V_R
6.0
4.0
2.0
1.0
.8
.6
.4
.2
.1
.08
.06
.04
.03
.02
.01
.008
.006
.001
MEAN % DRIFT
NOTE: 0.1% V_R CURVE NOT SHOWN. MEAN % DRIFT IS CONSTANT 0.02%, AND IS BASED ON ONE RESISTOR OUT OF TOLERANCE.
100
200
300
400
500
600
700
TIME (HOURS)

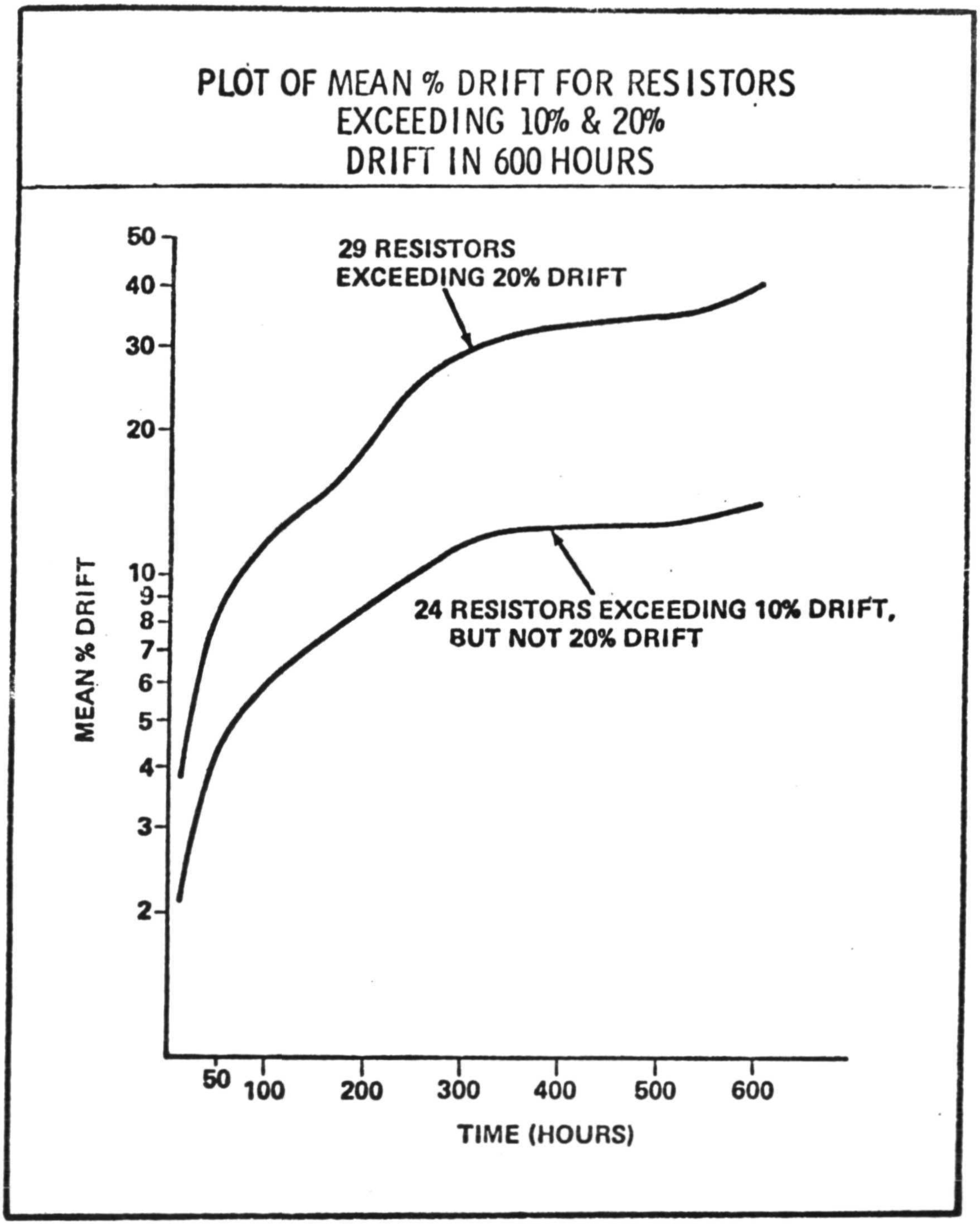
4

CHART 2



ACCUMULATIVE % POPULATION
CROSSING DEFECTIVE THRESHOLDS
POPULATION = 3067 RESISTORS
0.2% THRESHOLD
1.0% THRESHOLD
5.0% THRESHOLD
10.0% THRESHOLD
20.0% THRESHOLD
% DEFECTIVE
0
1
2
3
4
5
6
7
8
9
10
15
20
0
100
200
300
400
500
600
700
TIME (HOURS)

CHART 3


PLOT OF MEAN % DRIFT FOR RESISTORS
EXCEEDING 10% & 20%
DRIFT IN 600 HOURS
29 RESISTORS
EXCEEDING 20% DRIFT
24 RESISTORS EXCEEDING 10% DRIFT,
BUT NOT 20% DRIFT
MEAN % DRIFT
50
40
30
20
10
9
8
7
6
5
4
3
2
50
100
200
300
400
500
600
TIME (HOURS)

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May 1, 1973 TM X-64754

APPROVAL

VAMISTOR RESISTOR INVESTIGATION
REPORT

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

D. Grau, Director
Quality and Reliability Assurance Laboratory

K.L. Heimburg, Director
Astronautics Laboratory

F.B. Moore

B. Moore, Director
Astrionics Laboratory

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S&E-QUAL-E, Mr. E. Smith
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